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Boston Board of Water Commissioners

BROOKLYN WATER WORKS.

REPORTS

BY

MECHANICAL ENGINEERS

ON TRIALS OF DUTY

MADE IN 1857 AND 1859,

UPON THE

BROOKLYN, HARTFORD, BELLEVILLE, AND CAMBRIDGE PUMPING ENGINES.

NEW YORK:
HOSFORD & CO., STATIONERS AND PRINTERS,
Nos. 57 AND 59 WILLIAM STREET.
1860.

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Eng 978.57

1862. June 4
Gift of
Wm. Ezra Worthen
of New York City.
(Class of 1838.)

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PREFATORY.

The reports which follow are printed by order of the Board of Water Commissioners, both as presenting information of special interest to their fellow-citizens and as contributions, which they have not felt at liberty to withhold, towards the elucidation of a subject rendered frequently obscure to the general reader, more by the unreasonable claims and assertions of inventors and experts than by the inherent difficulties of the subject itself.

The report latest in date is printed first in order, because of its more immediate application at this time, in connection with the pumping-engine lately built and now in operation at Ridgewood Reservoir, upon which the city is at present wholly dependent for its supply of water, until a second one can be built.

The causes which led to the experimental examination of other pumping engines may not be familiar to all, and will therefore be briefly stated.

The contract of H. S. Welles & Co. for the entire works, includes the construction of two steam-pumping engines, each of capacity to deliver ten millions of New York gallons in sixteen hours (=22.236 cubic feet per second), under a lift by construction of 162 feet and through a 36-inch main, 3,400 feet in length.

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The contract describes and specifies a single acting beam-engine, of the kind usually known as the Cornish Engine.

The capacity of engine prescribed is unusually large. The diameter of cylinder required would exceed that of any other pumping-engine here or in Europe, except the Leeghwater engine. The horse-power exceeds any of these, the Leeghwater included. Such an engine of the Cornish variety, with a stroke of ten feet, would have required a cylinder, it is estimated, of 126 inches diameter, and a pump or plunger of 54 inches diameter.

Four of the most prominent machine establishments of the country (the Novelty Works, the Hartford Works, the West Point Foundry, and Morris & Co., of Philadelphia), estimated severally the diameter of the steam cylinder at 111, 120, 136 and 160 inches; three of them advised against the construction of so large a machine, and advised its division into at least two parts, making four engines instead of two. On the other hand, an engine of novel construction, combining ingeniously certain old inventions with much that was new, had been built, and was in use at Hartford, Ct., supplying that city with water. This engine was confidently asserted to be superior both in action and economy to the Cornish Engine. It had acquired considerable reputation and notoriety among engineers, and those interested in it presented strong claims to be permitted to compete for a machine of the capacity required for the Brooklyn works.

The above considerations, and others of similar import, induced me to advise that the engineering talent of the country should be invited to compete for the construction of the required machine, under certain restrictions, which will be best understood by reference to the notice to machinists then circulated from this office, of which the following is a copy:

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"NASSAU WATER COMPANY, BROOKLYN, N. Y.

MEMORANDUM TO MACHINISTS

Designing to propose for the Construction of the two Pumping Engines required on the above Water Works.

"The Engines are proposed to be of the Cornish class; but any other plan of Engine may be submitted, and will be considered, that will perform the same duty as efficiently, and as economically.

"Each Engine must be competent to perform, with ease, the following duty:

"To deliver into a Reservoir, situated 170 feet above the pump well, Ten Millions N. Y. gallons daily, in sixteen hours, through a 36 inch main, 5,800 feet in length.

"The N. Y. gallon of water weighs 8 lbs.

"To be each connected with not less than three Boilers, by a sufficient Steam Pipe, &c.

"To be provided with two Worthington Steam Pumps No. 5, properly connected with every Boiler.

"To be provided, each with an Air Chamber, built of Boiler Plate Iron, of not less than 4,100 C. feet capacity.

"The person proposing to build the Engine, may specify a different sized Air Chamber or a Stand Pipe, if he consider the last essential to the successful working of his Engine, giving his reasons accordingly.

"The duty of each Engine, with their boilers, to be further tested, by the standard of not less than 600,000 lbs. of water, raised one foot high, with one pound of coal.

"The iron and composition work of each Engine, all the materials used, and the workmanship and finish to be in all respects thorough, and the first of its class; the dimension, character, power, and action of the separate parts and conveniences, to be of the most approved

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description in use, on the class of Engines required; and these and every thing connected with the Engines, to be subject to the inspection and approval of the Engineer, of the said Nassau Water Company.

"The builder of the Engine to furnish every thing necessary to the placing it in position for work, and in the best working order, except the stone work of its foundations, which will be prepared for it, to suit the plan adopted.

"The builder to deliver and put up the Engine in its proper place, connecting it with the 36 inch main aforesaid.

"Plans in detail of the Engine proposed, shall accompany each offer, with a description of the parts, material, finish, conveniences, &c., understood and included in the offer.

"Offers and plans may be addressed, until the first of October next, to H. S. WELLES & Co., No. 4 Wall Street, New York, or to J. P. KIRKWOOD, Engineer, Nassau Water Co., Brooklyn, N. Y., of whom further information may be obtained.

"One of the Engines must be put up, and in all respects ready for the required duty, on or before the 1st of January, 1858, and the second, on or before the 1st of January, 1859."

Twelve offers for furnishing the required power followed this notice, founded on varieties of single acting and double acting beam engines, and of some direct-action engines. The different plans of these were carefully examined and analyzed at my request, by Mr. Samuel McElroy, who reported in favor of the double acting beam engine of Mr. William Wright of Hartford, as possessing certain advantages over all the others. This is the plan of engine since constructed, except that the steam cylinder has been built of 90 inches diameter instead of 100 inches as first proposed.

The notice to machinists above referred to, contains the following paragraph:

"The engines are proposed to be of the Cornish class; but any

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other plan of engine may be submitted, and will be considered, that will perform the same duty as effectually and as economically."

To ascertain whether an engine upon the model of the Hartford machine (which still claimed for itself the precedence), would perform as well and economically as the Cornish engine, it was necessary to make an experimental trial of the two. The Belleville engine, as the best specimen of a Cornish engine in the United States was selected to represent its class; and Mr. Brevoort and myself were authorized to employ Mr. C. W. Copeland and Mr. W. E. Worthen, both well known mechanical engineers, as experts to make the experiments. Their report is the second in order of these papers.

Mr. Worthington's offer to build a pumping engine after the model of the engine built by him for the Cambridge water works, led, for the same reasons, to an experimental trial of that engine, by Messrs. Morris and McElroy, whose report is the third in order. Mr. McElroy having afterwards made a separate statement of that experiment, founded upon what he considered a more correct mode than the ordinary one, of estimating the "duty" and showing a less favorable result than appeared in his joint report with Mr. Morris, a second trial of the Cambridge engine was directed to be made by a new Board, consisting of Mr. Frederick Graff and Mr. Erastus W. Smith; their report is fourth in order.

The last report of the series gives the result of a second trial of the Hartford engine, made at the desire of Mr. Wright. The second trial was conducted, with Mr. Wright's consent, by Mr. Graff and Mr. Worthen, and gives the results by two modes of estimating the fuel consumed; experiment No. 1 following what Mr. Wright considered the best mode, and experiment No. 2 being in accordance with that pursued by Messrs. Copeland and Worthen.

The reader is reminded that the object of these trials was to ascertain the working merits of the engines tried, as compared with the class of engine defined in the contract. In no other way could the

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assertions of the parties desiring to build engines upon these models, have been satisfactorily confuted or sustained.

The results furnish a sufficient basis upon which to form a fair judgement, not however, by a simple comparison of these results, but after some allowance made for difference in size, it being a well established fact that an engine of 200 horse power will perform double the work of an engine of 100 horse power, at less than double the expenditure of fuel; in other words will show a higher "duty."

The term "duty" has been applied to a conventional measure of the economical value of an engine, as regards fuel simply. The true economic value must include the elements of first cost, attendance, maintenance and repairs as well as fuel. A high duty might therefore be shown by an engine in other respects deficient, and it is only when all the characteristics alluded to work profitably together that the machine takes high rank.

The report of Messrs. Copeland and Worthen gives various modes of estimating the "duty," the most usual of which seems to be that form of estimating it which obtains at the mines, called in that report the Cornish mode. This gives the engine the full stroke of the pump, without deduction for leakage and other losses there, and, on the other hand, gives the engine no credit for the friction of the water in the pipes. At the mines the one may about balance the other, and where there are so many engines to be reported, a more correct mode might demand a nicety of observation which would defeat the system of monthly reports.

In making "duty" trials of pumping-engines of city water works, a different course is necessary to admit of a fair comparison of results.

If the friction of the main is not credited to the engine, an engine which works into a small main will compare unfavorably with an engine, in all respects alike, working into a large main. The results in this case would be false, as tests of the efficiency of the machines, and to make them true it is necessary to include the work due to

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water friction, whether that arises from differences in length, or in size of pipe, or both combined. In the same manner the engine should have credit only for the water delivered by the pump, not for the length of stroke. In some pumps the loss of action does not exceed two per cent., while in others it reaches ten per cent. Where the engine pumps into a reservoir the actual delivery of the pumps per stroke can be ascertained very closely; where this is not the case other modes of appreciating the losses can be applied.

In the experiments lately made on the Brooklyn engine my desire was that the length of stroke for the pump should be estimated from the actual delivery of water into the reservoir, and not by the measured stroke, but an obscurity of language in the paper agreed upon between the parties, as to the mode of taking the duty, gave the referees a different impression, and led them to credit the engine with the measured stroke. The losses at the pump in this case were found to be but 1.8 per cent., and the "duty," with this correction, would still have exceeded the contract provision.

The resulting "duties" of the different experiments described in these reports I have reduced to a common standard, upon the basis above referred to, viz: that which allows the engine the friction of the delivering main, and allows only for the water actually delivered by the pumps. The reports furnish me with the means of presenting the "duties" in this way, except in the case of the Cambridge engine, where the water was not measured in the reservoir, and in the case of the Philadelphia engine, tested by Mr. Graff, which I add as of interest in this connection, where also the water was not measured at the reservoir. In these two cases I have allowed five per cent. for losses at the pumps. The Philadelphia engine is not supplied with Cornish boilers.

The duties thus estimated are as follows, in feet x pounds of water for one pound of coal consumed:

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Date of Experiment	Length of Trial: hours		lbs. lifted one foot high
Jan. 1860...	26	Brooklyn engine.....	601,407
Jan. 1857...	12	Belleville* " Cornish.....	628,233
Jan. 1857...	8½	Hartford* " Crank.....	587,793
July, 1857...	17¾	Hartford " 2d trial, 1st exp..	614,426
July, 1857...	12	do. " 2d trial, 2d. exp..	646,994
April, 1857..	9	Cambridge " Double Cylinder.	669,411
June, 1857..	14¾	Cambridge " 2d trial, do.....	675,746
June, 1856..	48	Spring Garden, Phil., Cornish....	589,053

The mode of estimating the fuel used under the duty trial of the Brooklyn engine, differed from that pursued on the trials of the other engines. By the mode alluded to, which Mr. McElroy and Mr. Wright esteemed the best, Mr. M. made the duty of the Cambridge engine, assuming seven per cent. loss of action on the pumps, 587,645. The second trial of the Hartford engine, estimated in this way, gave 614,426. In either way, where the time given to the experiment is short, a certain margin of error may easily creep in, which the judgment of the experimentalists must be relied on to counteract.

The characteristics and general dimensions of the several engines will be gathered from the proper reports. All of them use the steam expansively, though none of them to as high a degree as seems to be customary with the same classes of engines in England.

* See Note A.

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The three Cornish pumping engines of the East London Water Works, (the two first, erected under the direction of Thomas Wicksteed,) cut off respectively at one third, one fourth, and the latest at about one fifth of the stroke. The Victoria, another Cornish pumping engine, built at Lea Bridge, is also said to cut off at one fifth. The Belleville engine cuts off usually at one half, as will be seen by reference to its steam cards.

The following dimensions of several of the London Cornish pumping engines are noted for reference:

Name	Stroke Feet	Steam cylinder diameter	Pump pole diameter	Capacity per stroke	
				C. feet	Imp. gallons
Cornish.. ..	10 feet.	80 inches.	41 inches, (9 feet).		
Wicksteed..	11 "	90 "	44 "	112.	697.7
Ajax.....	10 "	72 "	36 "	70.	436.
Victoria....	11 "	100 "	50 "	150.	934.5
Southwark.	11 "	112 "	50 "		

These engines make from nine to ten strokes per minute.

Simpson's double cylinder engines at the Chelsea and Lambeth stations, cut off the steam at half stroke, in the small cylinder. Their expansion is estimated to reach eight times the initial steam.

The application expansively of steam of high pressure is essential to economy of fuel, but the principle usually involves the intervention of some contrivance or receptacle to receive and expend gradually the excess of power communicated at the commencement of the stroke. The engines described in the accompanying reports are ex-

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amples of three varieties of mechanism admitting of the use of expansion in different degrees.

In the Cornish mining engine, from which the water works engine has been copied, the conditions of the work to be performed furnish the weight or mass, to which steam of high pressure can communicate the momentum necessary to facilitate its action expansively. Some of the shafts of these mines are 1,800 feet in depth, and the timber pump-rods of this length are necessarily large and heavy. The weight of the rods exceeds in such shafts the column of water to be raised by many tons—in some cases by fifty tons. This excess of weight, after allowing a sufficient difference for friction and velocity, is counterbalanced at the steam end of the beam, or by independent beams, as convenience dictates.

The weight of the rods being in excess of the column of water, the lifting of their weight forms the work of the engine: the gravity of their descent operating, by auxiliary rods, upon a series of plunger pumps, forces up the column of water which it overbalances, delivering at each stroke the required proportion thereof at the mouth of the pit.

Here, therefore, the circumstances of the work to be done furnish the steam-engine with a sufficient accumulator of force upon which profitably to use the principle of expansion.

The Cornish pumping-engine for water works follows the simplicity of mechanism of the mining-engine, in applying steam to but one side of the piston, and lifting a weight, instead of lifting water, the said weight being adjusted so as to exceed the weight of the column of water to be raised, by a sufficient increment for friction and velocity.

The weight referred to is contained in an iron cylinder placed immediately over the pump, technically called a plunger.

Here, as in the mining engine, the principle of the machine furnishes a mass of matter by which to use high steam economically,

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without artificial addition, though additional weight is sometimes applied to increase the expansive capacity of the machine.

The water column set in motion by the weight or plunger above mentioned, and not by the direct action of steam, is started very slowly, but rapidly acquires velocity until brought to absolute rest at the end of each stroke by the cushioning of the steam piston upon a body of steam. The direct action, in other machines, of steam upon water, pursues an opposite course, in accordance with the movement of the steam itself in the steam cylinder. The motion to obtain expansion is rapid in the first quarter of the stroke, gradually slowing thence to the end of the stroke. This action upon the water would be harsh compared with the other, but the use of air vessels in a measure neutralises the evil.

The Hartford engine is an example of the second variety of mechanism by which steam is used expansively.

In this case the conditions of the work do not furnish the mass of matter required; for a column of water alone, has not been found competent to perform this service satisfactorily. The fly wheel, therefore, is brought in as an artificial accumulator and dispenser of the surplus power given out by steam of high pressure at the beginning of the stroke. In this case the fly wheel is not applied to produce uniformity of movement, for this is not desirable in a pumping engine, but as a convenient reservoir for the pulsations of power referred to.

The fly wheel possesses certain advantages over the plunger in this respect, and admits of the expansion of steam being carried farther under the ordinary circumstances of the two cases than in the Cornish arrangement, at the expense not probably of greater weight in motion, but of greater momentum, under a leverage which strains unequally the machine.

If the beam of the Cornish engine be considered a reciprocating fly wheel, it will follow that the power of the steam is applied in the

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Cornish machine at the periphery of the wheel, whereas in an ordinary fly wheel engine, it is applied inside of the periphery at a point one fifth or one sixth the length of a radius from the center. At this point, the steam piston (moving at the same velocity in each case), will communicate a high velocity to the periphery of the wheel, resulting in a higher momentum in action. The steam applied at this point *within* the fly wheel meets a greater relative resistance than in the other case, admitting of the expenditure, within the same time, of greater power to produce the same effect, and hence, of the application of steam of higher pressure at the commencement of the stroke. The Hartford engine cuts off at one eighth, whereas the Belleville engine cuts off at about one half, though the English examples of the Cornish engine cut off more usually at one fourth.

The third variety of mechanism (in these Reports) adapted to the use of steam of high pressure expansively, is the double cylinder engine, similar in principle to Woolf's, but much improved in details.

The agency of weight in motion, in the application of expansion, has been so usual and serviceable, as to have become considered by many, a condition of this principle of economy, as much as the use of steam of high pressure; but it is evident that by the use of two cylinders, steam can, within certain limits, be profitably expanded, without other artificial assistance, and with a more equable movement than in the other case; with the additional assistance of a certain amount of weight in motion, the expansion can be carried further. Without weight in motion, however, or any similar artificial aid, it will not be denied that the double cylinder engine of these Reports produces very respectable results, and compares very favorably with the other machines.

Mr. Worthington's double cylinder engines use the initial pressure during the full stroke of the small cylinder, expanding into the large one.

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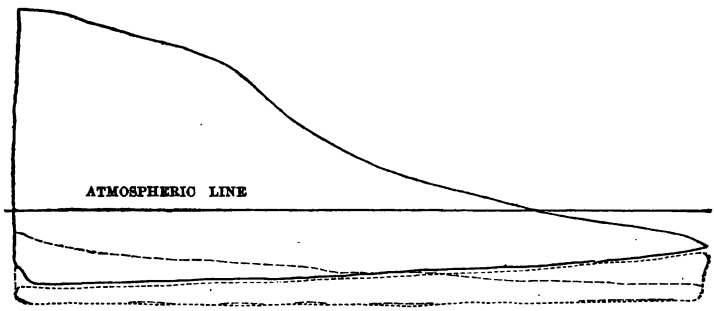
In Simpson's double cylinder engines at Lambeth and Chelsea, near London, the steam is cut off at half stroke in the small cylinder, expanding the remainder of the stroke, and thence continuing the expansion in the large cylinder. The expansion is about eight times. These are beam engines, with fly wheel attached.

The following steam card of the Chelsea engine was obtained by Mr. Graff when in London. It may be compared with the steam card of the Cambridge double cylinder engine; the last it will be remembered works without beam or fly wheel.



Indicator diagram taken from Simpson & Co.'s improved Double Cylinder Pumping Engines:

The card from top of small cylinder is shown thus ———
The card from bottom of large cylinder is shown thus - - - - - -
The card line from top of large cylinder is shown thus – – – – –
Steam pressure in boilers, 40 lbs. per inch.
Vacuum in condenser, 28.5 inches of mercury.
Scale of indicator 20 lbs.—¾ inch.
Capacity of large cylinder—4 times capacity of small one.

A trial of the duty of these Chelsea water works pumping engines was made by Mr. Joshua Field, C. E., of London, on 9th August, 1857. I am indebted to Mr. Graff for the following notes of the trial.

These engines are four in number, of precisely the same dimensions each. They pump through 5¾ miles of 30 inch main to a reservoir 170 feet high.

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Large cylinder, 46 inches diameter.
Small do. 28 do. do.
Stroke of large cylinder, 8 feet.
Do. of small do 5 do. $6\frac{5}{8}$ inches.
Pressure of steam in boilers, 40 lbs.
Extent of expansion, 8 times.
Diameter of pump barrels 24 inches.
Length of stroke of pump, 6 feet 11 inches.
Water delivered per stroke each pump, 135.78 gallons Imperial.
Duration of experiment, 24 hours.

Strokes per counter, made by A and B engines..	20,744
Strokes per counter, made by C and D engines.....	20,824
	41,568
	2
Equivalent number of strokes of one engine.....	83,136

135.78x83.136=11,288,206 gallons.
Lift, per mercurial guage, in engine house, $234\frac{3}{4}$ feet.
Lbs. raised one foot high, 112,882,060x$234\frac{3}{4}$=26,499,063,585.
Coal consumed, 255 cwt.
Lbs. raised one foot high by 112 lbs. coal, $\frac{26,499,063,585}{255}$ = 103.9 millions.
This is equivalent to a duty of 92.64 millions for 100 lbs. coal.

Mr. Graff has called my attention to a paper printed lately by Mr. Thomas Wicksteed, Civil Engineer, of London, by whom the first and the second Cornish pumping engines used for that city were erected, and who in 1841 published his experimental inquiries into the useful effect of the Cornish and Boulton, and Watt pumping engines. The results of the experiments made by him at that time to ascertain the duty of the Cornish engine, are compared with the average duty of eleven years work of the same machine, and give a fair idea of the economic value of the machine in ordinary hands and with ordinary fuel, as compared with its economic capabilities when used as faithfully and carefully, as it is used, during a short experimental trial, and as it can always be used in proper hands.

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EXTRACTS FROM MR. WICKSTEED'S PAPER.

"The author proposes to show, in the first instance, what was the actual *average* 'duty' performed, *during a period of eleven years*, by the Cornish Engine, erected according to his advice in 1839, at the East London Water Works, Old Ford, as compared with that performed in 1840, during a trial lasting *five days*, conducted with great care, and on which occasion the *best small Newcastle coals* were provided and used under the boilers. During the trial the steam was cut off at one-third of the stroke, and this arrangement was continued until the end of the year 1850, which was the last whole year that the author had it under his personal supervision."

"In the trial made of the Cornish engine at the East London Water Works, the particulars of which will be found in the author's 'Experimental Inquiry,' published by Mr. Weale in 1841, the duty, or rather useful effect obtained in pounds lifted one foot high per cwt. of coals consumed under the boilers, is stated to be equal to 97,146,268 lbs. when the steam was cut off at one-third of the length of the stroke.

"The trial lasted 117¾ hours, during which the engine made 49,302 strokes; the stroke of the pump was kept as nearly the same length as possible, and averaged 9 feet. The water raised per stroke was equal to 14.28 imperial barrels; the average pressure under, or height to which the water was raised was 108 feet, and the evaporative power of the coals consumed was equal to 8.524 lbs. of water per pound of coals, from 80°.

"During a period of eleven and a half years, from midsummer 1839, when the engine was first set to work, to Christmas 1850, the number of strokes made was 30,959,220, and the weight of small Newcastle coals consumed under the boilers was 10,485 tons, or 209,165 cwts., being at the rate of 148 strokes per cwt. The average length of the pump stroke was 8.56 feet, the water raised per stroke was equal to 13.6 imperial barrels, being 5 per cent. less than during

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the trial. The average pressure under which the water was raised was equal to 106.5 feet, being about 1.4 per cent. less than during the trial, and the average evaporative power of the small Newcastle coals consumed under the boilers was equal to 7.127 lbs. of water per lb. of coal, instead of 8.524 lbs., which was the evaporative power of the best small Newcastle coals consumed during the trial.

"The average duty or 'useful effect,' in fact, during the eleven and a half years, was equal to.....	77,385,115
With *best Newcastle small coals*, evaporating 8.524 lbs. of water per lb. of coals, it would have been.....	92,553,770

"The 'Wicksteed Engine,' designed by, and erected under the superintendence of the author, in 1847, at the East London Water Works (similar in size and power to one previously designed by him for the Grand Junction Water Works Company at Kew), has a cylinder of ninety inches diameter, and a plunger pole of forty-four inches diameter, and both eleven feet stroke; but the average length of stroke during the years 1848, 1849 and 1850, was only ten feet six inches, or about ninety-five per cent. of the full stroke. The number of strokes made during the three years was 6,990,392. The water raised per stroke was equal to 19.18 imperial barrels. The weight of small Newcastle coals consumed under the boilers was 3,204¾ tons, or 64,092 cwts., being at the rate of 109.06 strokes per cwt. with coals evaporating upon the average during the three years 6.77 lbs. water per lb. of coals; but the evaporative power of the coals upon the average of eleven and a half years, was equal to 7.127 lbs.; with such coals the number of strokes would have been equal to 114.81 per cwt.; the average pressure during three years was equal to 103 feet.

	Lbs. per cwt.
"The average duty or 'useful effect,' during the three years, was equal to.....	681,868,52
With the best Newcastle small, it would have been.....	97,916,000
With the best Welch coals, it would have been.....	109,047,000

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"In the 'Wicksteed Engine' the steam was cut off at one-fourth, and in the Cornish at one-third the length of the stroke; hence the superiority of the former over the latter."

	Lbs. per cwt.
"The average duty of the two Engines, with the small Newcastle coals actually used, will be.....	79,626,820
With best small Newcastle coals.....	95,234,885
With best Welch coals.....	106,061,096

.... "the price of coals in the market is not in proportion to the evaporative power of the coals, and therefore the duty done, *per pound sterling*, should be taken into account as well as the duty per cwt. of coals."

.... "the cheapest coals in the market frequently produce the greatest effect *per pound sterling*, which, after all, is the only legitimate test of their commercial value."

"The following Table shows the pounds of coals consumed per horse-power per hour, the price per ton of the coals used, and the actual cost (at the dates given in the Table) of coals, stores, and labor per horse-power per annum of several engines, working at the rate of twelve hours per diem, six days per week.":...

"The author obtained the data for this Table during the period he acted as Consulting Engineer to the several parties. The Vauxhall Water Works were amalgamated with the Southwark Water Works by the advice of the author, and at the amalgamated works, and also at the Grand Junction, Kent, and Hull Works, Cornish Engines have been erected since the dates given in the Table.

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	Lbs. of Coals, per Horse Power	Price per Ton	Cost of Coals, per Annum	Cost of Stores, per Annum	Cost of Labor, per Annum	Total Cost, per Annum, per Horse Power	
						Sterling	Dollars at $4 65 per £
		s. d.	£	£	£	£	
1st. The Hull Water Works, two double engines, 1845.....	23.75	7 3½	14.468	2.351	5.991	22.810	106.07
Do. Do two direct action, 1847.....	6.10	"	3.723	1.361	3.800	8.884	41.31
2d. The Vauxhall Water Works, two double engines, 1843 and 1844.....	11.50	11 4½	10.973	1.391	4.419	16.783	78.04
3d. The Kent Water Works, two single acting, 1834.....	8.81	22 1	16.310	2.188	3.810	22.308	103.73
4th. The Grand Junction, three single acting, 1843, 1844 and 1845.....	7.49	18 5	11.568	1.327	2.537	15.432	71.76
5th. The East London Water Works, four single acting, 1830.	8.90	16 10	12.566	1.654	2.102	16.322	75.90
Do. ten years, from 1831 to 1840.....	7.60	18 5	11.738	1.195	2.060	14.993	69.72
Do. ten years, from 1841 to 1850, two engines.....	6.20	12 11½	6.737	1.096	2.086	9.919	46.12
Do. two Cornish engines, the two averaging seven years, to 1850.....	2.99	11 8½	2.933	0.784	1.852	5.569	25.89

Note: The figures in the 3d, 4th and 5th columns of this Table, represent pounds sterling and decimals of a pound.

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"It should be observed that although the coals and stores are, or should be, in proportion to the horse-power and hours worked, the *labor* will vary," ..... "in fact, each case and each locality may lead to a variation in the cost per horse-power, notwithstanding the Engine may be equally good in principle and construction; to the experienced man, however, it may be useful as a statement of ascertained facts, and may assist in estimating the cost per horse-power per annum."

Messrs. Copeland and Worthen supposed that the ordinary duty of the engines experimented on by them, might differ ten per cent., from their performance on a short trial, made with great care, under the eyes of their respective builders. Mr. Wicksteed's results show a larger loss; caused mainly, however, by the inferior quality of coal used during the eleven and a half years referred to. Using the same quality of coal as in the experiment, the difference, as shown by Mr. Wicksteed's statement, would not have exceeded five per cent.

JAMES P. KIRKWOOD.

Engineer's Office, Brooklyn,
20th. February, 1860.

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The following notes, which are furnished me by Mr. L. B. Ward, show the "duty" of the Belleville Engine after allowance is made for the condensing water extracted from the main: also the duties of that and other engines, under a uniform standard of evaporation.

NOTE A.

"The water for condensation at Belleville was taken from the rising main, and should enter into the estimate of the duty of the engine. The average quantity of water evaporated into steam during the trial was 9.816 lbs. for one pound of coal burnt. As the quantity of caloric contained in steam of the pressure used, is represented, according to Regnault's observations, by 1194 deg. Far., for condensing and reducing 9.816 lbs. to the temperature of the feed-water, 92.3 deg., there would be required 179.4 lbs. of water of a temperature of 32 deg., which was that of the water pumped. This quantity of water delivered by the pump against the head of 164.566 feet, adds 28,543 to the duty in the above given table, increasing it to 656,776.

"The report made by Messrs. Copeland and Worthen affords data for estimating the efficiency of the Engines which they tested, by taking the pound of water evaporated as steam, in place of the pound of coal consumed, as a basis of comparison; this will exhibit the merits of the Engine independent of the quality of the coal used, and the varying conditions under which the steam is made.

"At Belleville the evaporation is given at 9.816 lbs. of water per 1 lb of coal; this figure should be increased to 10 lbs. to include the small quantity of water condensing in the jacket of the cylinder and returning to the boiler: the amount of this condensation under various conditions of working is given in Wicksteed's 'Experimental Inquiry.'

"The evaporation at Hartford was 10.81 lbs. of water per 1 pound of coal.

"The figures given below show this duty for the Belleville and Hartford Engines on the trial referred to. The duty per pound of water is derived from the corrected duty already given for the pound of coal consumed, by dividing that by the number of pounds of water evaporated per pound of coal in each case. The duty per pound of coal is also given, assuming a common standard of evaporation for both, of 10 lbs. of water per 1 lb. of coal."

	Duty ℔ lb of water	Duty ℔ lb of coal
Belleville Engine.....	65,677	656,770
Hartford "	54,375	543,750

NOTE B.

"The average duties of Mr. Wicksteed's Engines, estimated as in Note A, are given in the following table; also the estimated average duty of the Belleville Engine, obtained by reducing that given in Note A by 4.75 per cent., which the results stated by Mr. Wicksteed in his pamphlet indicate was the amount of loss in average yearly duty (when calculated for the same quality of coal in both cases), compared with the duty obtained during the experimental trial (1841) for the Engine of his experiments.

"As the Engines referred to are all of the Cornish class, and of similar construction, the table has been made to exhibit for the different Engines the

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rate of expansion used, and the mean pressure of steam in the cylinder, (measured from absolute vacuum.)

"It will be found that in amount of 'duty' the Belleville and 'Wicksteed' Engines both fall considerably below what is due to their relative rates of expansion, when compared with the 'Cornish.' It should be noticed however, that in the statements of the duties of Mr. Wicksteed's Engines, the discharge of the pumps appears to be estimated at their full capacity for the given length of stroke; if the same were done for the Belleville Engine the results would be 4.2 per cent. larger than given in the table, making the duty per pound of water 65,307, or 653,070 per pound of coal."

	Cutting Off at	Mean Pressure in Cylinder	Duties	
			Per lb. Water	Per lb. Coal
Belleville Engine.....	$\frac{1}{3}$	18.35 lbs.	62,558	625,580
"Cornish" "	$\frac{1}{8}$	14.0* "	96,947	969,470
"Wicksteed" "	$\frac{1}{4}$	....	102,563	1025,630

* Taken from the Diagram.

The diagram on the next page is taken from Pole's "Treatise on the Cornish Pumping Engine," and exhibits the action of the steam in the cylinder of the "Cornish" Engine of the table.

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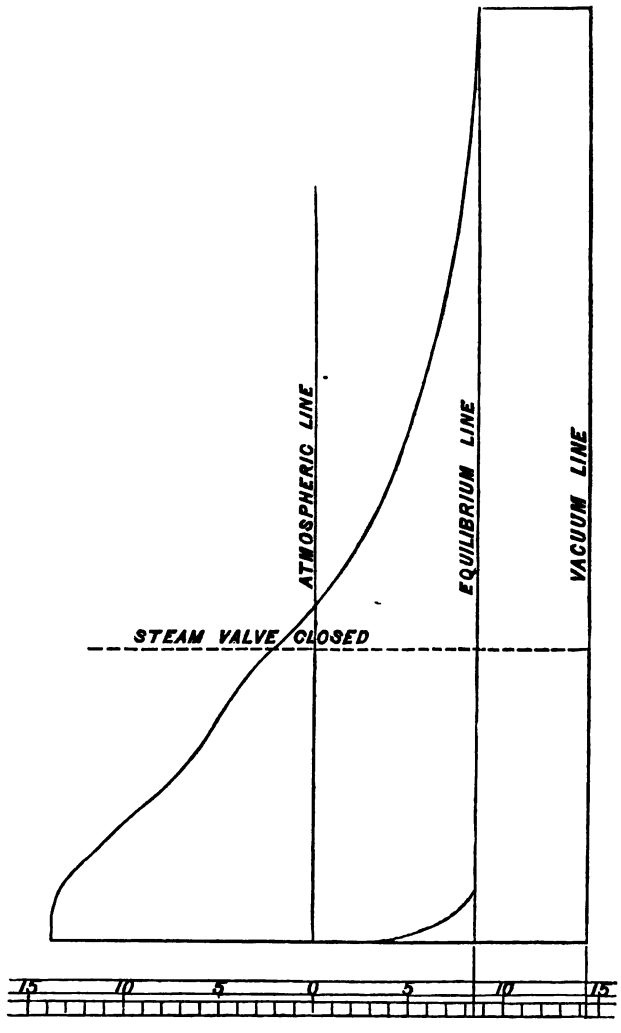

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REPORTS.

Report of Messrs. Smith, Graff and Worthen on the first Brooklyn Pumping Engine.

To Messrs. Brevoort and Kirkwood, Committee:

Gentlemen: Agreeably to your request, we have made a series of experiments on the Pumping Engine at Ridgewood, to determine whether it complies with the specifications and contract between the Nassau Water Company and H. S. Welles & Co., contractors; in conformity to the tests for required capacity and duty, agreed upon by James P. Kirkwood, Eng'r., on the part of the Nassau Water Company, and Wm. E. Morris, Eng'r., on the part of the contractors, May 30th, 1857; and approved by H. S. Welles & Co., contractors, and John H. Prentice, President, and J. Carson Brevoort, Secretary of Nassau Water Company. The method of test above agreed upon is an usual one, and we consider it fair and just to both parties.

The first experiments were made in reference to the "duty" of the Engine.

According to the contract and agreement: "The 'duty' of the Engines shall not be less than 600,000 lbs. (avoirdupois) raised one foot high with one pound of mineral coal, and is to be calculated in the usual way, as follows:

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"The friction of the water in the pipes shall be ascertained by reliable gauges, and when so ascertained, shall be added to the weight of water due to the height between the pump well and point of delivery. The weight of the water to be taken at 62½ lbs. per cubic foot.

"The load on the pump piston, thus ascertained, multiplied by the length of stroke, in feet, and by the number of strokes, and divided by the number of pounds of coal consumed during the experiment, equals the 'duty.'

"This test, viz: of duty, to include not less than twenty-four hours consecutive work of the machine, and the Engine while under work shall deliver into the reservoir not less than its proper proportion of twenty millions of gallons in twenty-four hours, to be ascertained by measurement in the reservoir."

The friction of the water in the main was ascertained by an Allen Gauge (previously tested), placed at the top of the upper pump, and was found, including the static pressure to be 61 lbs. to the square inch, by an average; to which was added 13,077 lbs. for the difference of level between the position of the gauge, and the average level of the water in the pump well during the experiment, or 30.26 feet; making therefore, a total pressure on the pump piston of 74.077 lbs. per square inch.

No allowance is made for the friction of the water through the pumps and intermediate pipe.

The diameter of the lower pump was found to be a little less than 36 inches, while the upper exceeded this measure by about the same amount, the average has been taken at 36 inches; the diameter of the lower pump piston rod was 8¼ inches, the area of this section was taken from that of the

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lower pump, but there was no deduction from that of the upper pump. The sum of the areas of the two pistons is therefore 1,982.3 square inches. And the load on the pistons 74.077 x 1,982.3=146,842.83 lbs.

The number of strokes during the experiment was 14,923. The average length of stroke, as taken by observation, was 9.83 feet.

In firing, the Engine, after having been at work several hours, was stopped, the steam was blown off from boilers, and the fires were drawn; the firing then commenced anew, an account of the fuel to the end of the experiment was taken; when the Engine had exhausted all the steam, and stopped of itself, the grates were raked, and the quantity of coal separate from cinders and ashes was ascertained, and this was credited to the coal used, thus:

Wood 1,200 lbs., or equivalent of coal.....	600 lbs.
Total of coal fired.....	35,700 "
	36,300 lbs.
Less residuum of coal.....	870 "
Net quantity of fuel used.....	35,430 lbs.

$\frac{146,842.83 \times 14,923 \times 9.83}{35,430}$=607,982 lbs. ft., or "duty" of 1 lb. coal.

The experiments were commenced January 12th, 1860, at 11 o'clock and 6 minutes A. M., and ended January 13th, 1 o'clock and 11 minutes P. M. Duration of test 26 hours, 5 minutes. The quantity of water delivered at the Reservoir was measured both in the Reservoir itself, and by a weir as it flowed into the Reservoir; the following are the results:

By the Reservoir measures.....	15,521,719 galls.
" Weir "	15,603,117 "

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The gallon being the New York gallon of 7.8125 to the cubic foot.

By the requirement of the contract, the "duty" was to be 600,000 lbs. feet for 1 lb. of coal, with a capacity of 10,000,000 gallons raised into the Reservoir in 24 hours at the same time. It will be seen therefore, that the machine has complied with the contract requirements of "duty."

It was impossible for us while at Ridgewood, to get a Sealer of Weights to examine the platform scales, which we used; but he arrived soon after our departure, and has sent a certificate as follows: "As the index stood on my arrival, 60 lbs. of coal indicated on that index, weighed 59 lbs. avoirdupois." In our calculations no allowance has been made for this discrepancy, as the scales were well balanced during the course of the experiments, but seemed to have been thrown out of adjustment by an upset at the close. If the scales were as indexed by the weigher, throughout the test, about 1.7 per cent. should be added to the "duty" result.

By the contract and agreement: ten "millions of New York gallons of water to be raised into the Reservoir, in sixteen continuous hours forms the required capacity of" this machine.

"The water delivered to be measured in the Reservoir, making the proper allowance, if any, for absorption, leakage, and evaporation."

The experiments were commenced January 13th, at 7 o'clock P. M., and continued to January 14th, 11 o'clock A. M. Duration of test 16 hours.

The quantity of water was measured as before, both by reservoir and weir, with the following results:

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By Reservoir measures..... 10,293,102 galls.
" Weir " ..... 10,095,125 "

And therefore the machine in *capacity* complies with the contract.

In both series of experiments, allowance on Reservoir measures, has been made for absorption, leakage and evaporation, from observations taken before the commencement and after the conclusion of each test; and during the last experiments, deduction was made for rain fall from rain guage observations.

In regard to the materials and workmanship of the machine, the materials are, as far as we can judge, of excellent quality, and the workmanship superior, and creditable to the builders.

Respectfully submitted,

ERASTUS W. SMITH,
FREDERICK GRAFF,
W. E. WORTHEN.

JANUARY 17th, 1860.

Specimens of the steam and pump cards are appended, marked S S′ S″ S‴ and P.

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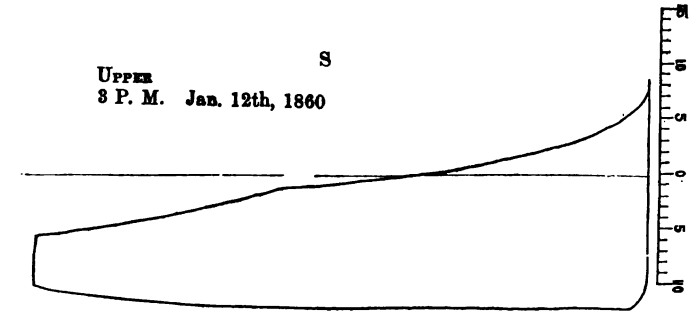

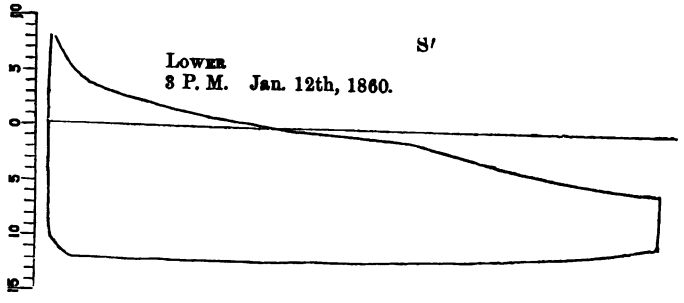

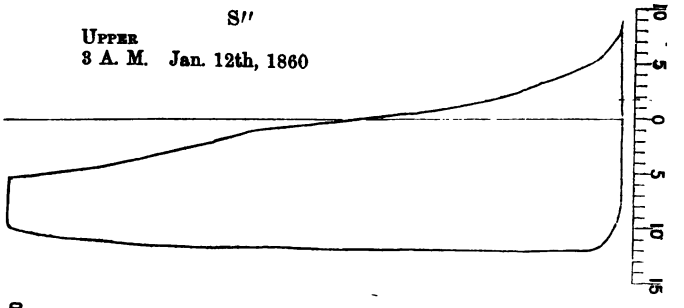

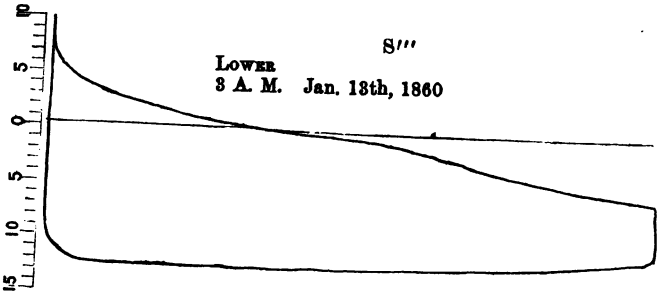

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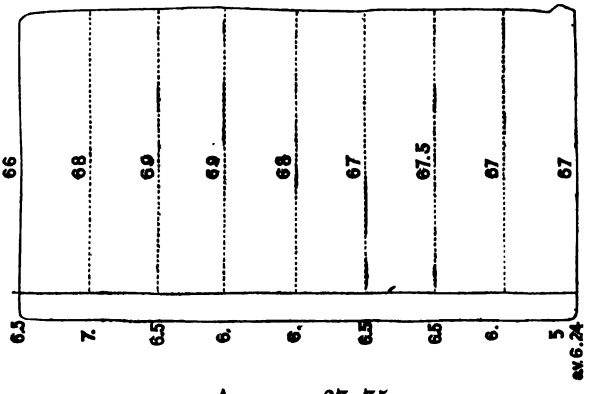
Lower, 3 P. M. Jan. 12, 1860.



Average 67.75

BROOKLYN PUMPING ENGINE.

Mr. McElroy's Notes of the Experiments made to Test the Duty. January 12 and 13, 1860.

JAN. 12.

Engine running from 5 A. M.

10.35′ A.M. Hauled fires. Counter 560,647.

10.40′ " Furnaces wooded with 1,180 lbs. Steam blown off.

10.45′ " Started fires.

11.06′ " Started Engine. Steam, 15 lbs. Well, 8′ 7″.

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JAN. 13.

1.9′ P. M. Engine stopped. Counter 575,612. Well, 7′ 9″.
Hauled fires and weighed contents.

Reservoir, Jan. 12. 11.15 A. M. 7′.216
" " 13. 1.15 P. M. 10′.789

Running Time — 26 h. 3 min. 1,563 min.

No. of double strokes — 14,965; average per min. 9.57

Quantity pumped — Res'r Prism....1,943,800 c. ft.
Leakage..... 54,262 "
Absorption..... 1,938 "
Total....2,000,000 c. ft.
Rate per 24 ℔s.....14,418,000 galls.
Delivery per stroke..... 1,044 "
Capacity " " (for 9′ 10½″) 1,062 "
Loss of action..... 1.69 ℘ cent.

Equivalent Lift.....170 ft.
Actual.....160 "

Fuel Account: Wood, 1,180 = 524 ℔s. coal.
Coal charged....35,105 "
35,629
" credited.... 856
Total burnt..34,773 ℔s.
Average per hour..1,331 "

Duty: 2,000,000 c. ft. × 62.5 ℔s. = 125,000,000 ℔s. × 170 ft. = 21,250,000,000 ft. lbs. ÷ 34,773 lbs. coal = 611,114 ft. ℔s.
Friction of Engine by cards.....8½ ℘ cent.

SAMUEL MCELROY,
Ass't Eng'r, B. W. W.

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Notes of Experiment made to Test the Pumping Capacity of the Engine.

JAN. 13. 5.30′ P. M. Fires lighted.
7.00′ " Commencement of trial. Well, 8′9″.
" 14. 11.00′ " End of trial. Well, 7′4″

Running Time—16 hours.....960 min.
No. of double strokes—9,708; average per min. 10.11
Average speed for four hours, per min.....10.36

Quantity pumped—Res'r Prism....1,291,216 c. ft.
Leakage..... 33,392 "
Absorption..... 1,192 "
Total....1,325,800
Per 16 hours.....10,357,812 galls.
" 24 " .....15,536,718 "

Coal burned.....26,528 lbs.
" " per hour (18 hours).. 1,473 "

SAMUEL MCELROY,
Ass't Eng'r, B. W. W.

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The Brooklyn Engine was built by Woodruff & Beach of Hartford, Conn., from designs by Mr. Wm. Wright, their Superintendent, and was patented by him, 15th November 1859.

It delivers at the rate of ten millions of gallons in twenty-four hours with ease and regularity.

The following are dimensions, &c.:

Diameter of cylinder, 90 inches.
Length of stroke of piston, 10 feet.
Length of beam, 30 feet. Weight of do. 25 tons.
Height of center of do. above floor, 26 feet 3 inches.
Number of pumps, two: stroke of do. 10 ft.
Capacity of do., per double stroke, 137.657 c. ft.
Diameter of working barrel of do., 36 inches.
Diameter of auxiliary barrel of do., 54 inches.
The valves are of the double beat kind.
Double acting air pumps.
Diameter of do., 3 feet.
Stroke of do., 5 feet.
Diameter of air chamber, 78½ inches.
Height of air chamber, 25⅛ feet.
Height of do. above floor, 13 feet 10 inches.
Return drop flue boilers, three in number.
Diameter of do., 8 ft.
Length " 30 ft.
Total weight of Engine, boilers, and appurtenances, 440 tons.

Depth of bottom of pump well below floor, 37 ft. 3 in.
Ordinary depth of water in pump well when pumping, 7 ft.
Diameter of force tube, 3 ft.
Length " " 3,450 ft.
Equivalent "lift," 170 ft.

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Report of Messrs. Copeland and Worthen on the Belleville and Hartford Pumping Engines.

NEW YORK, January 30th, 1857.

JAMES P. KIRKWOOD, ESQ., ENGINEER, J. CARSON BREVOORT, SECRETARY, NASSAU WATER CO.

Gentlemen: In accordance with your note of November 11th ult., we have made trials of the actual duty performed by the Pumping Engines at Hartford and Belleville, and herewith submit the following report:

Previous to commencing the trials, due notice of our intention was communicated to the engineers of the different works, to the builders of the Engines, and to the patentee of the Hartford Pumps, with the suggestion that the machinery should be put in an order satisfactory to themselves, which suggestion was carried out at Hartford by Mr. Wright, for Woodruff & Beach; and by Mr. Worden, at Belleville, for the Cold Spring Works. These parties were present at the trial of their respective Engines during the whole course of the experiments.

The experiments were conducted as far as possible in the same order and manner at both places. The levels were taken by the same engineer, Mr. McElroy; the same assistants were employed as observers and in similar positions, and the same fireman was employed in firing. It was also the intention to have used exactly similar coal, but owing to the ice in the river the coal shipped to Hartford did not arrive in time; its place was therefore supplied by purchase from a yard at Hartford—a similar quality of Cumberland

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from George's Creek, but not from the identical mine with that forwarded and used at Belleville; it was somewhat larger, and in rather better condition than the latter. All requisite checks were applied to the observations, and although drawings and dimensions were furnished by the builders of the Engines, yet all important parts were subjected to measurement.

DESCRIPTION OF WORKS.

Sheet 1, represents the plan of the Works at Hartford, showing position of Engines, Rising Main and Reservoir.

Sheet 2, represents longitudinal and cross section of Boiler.

Sheet 3, represents a section of Pumps.

As will be understood by the drawing, the boiler is a drop-flue boiler, and very well clothed. The chimney is very high and the draft good, but the damper is generally opened but very little.

The back-end of the boiler and all steam connections were felted.

The Engine is a double acting, condensing, crank and beam Engine, with a single cylinder of 32⅝-inches diameter, five feet stroke, with an adjustable cut-off of Wright's patent. The injection water is taken from the well. There is a heavy fly-wheel of twenty-two feet diameter on the crank-shaft, and power is communicated by a pinion of twenty-seven teeth on the end of this shaft, gearing into a spur-wheel on either side of eighty teeth, and on each spur-wheel shaft are two cams, each giving motion to a set of pumps by means of bell-cranks. Each set of pumps consists of two pistons or boxes in one chamber or cylinder, one above the other,

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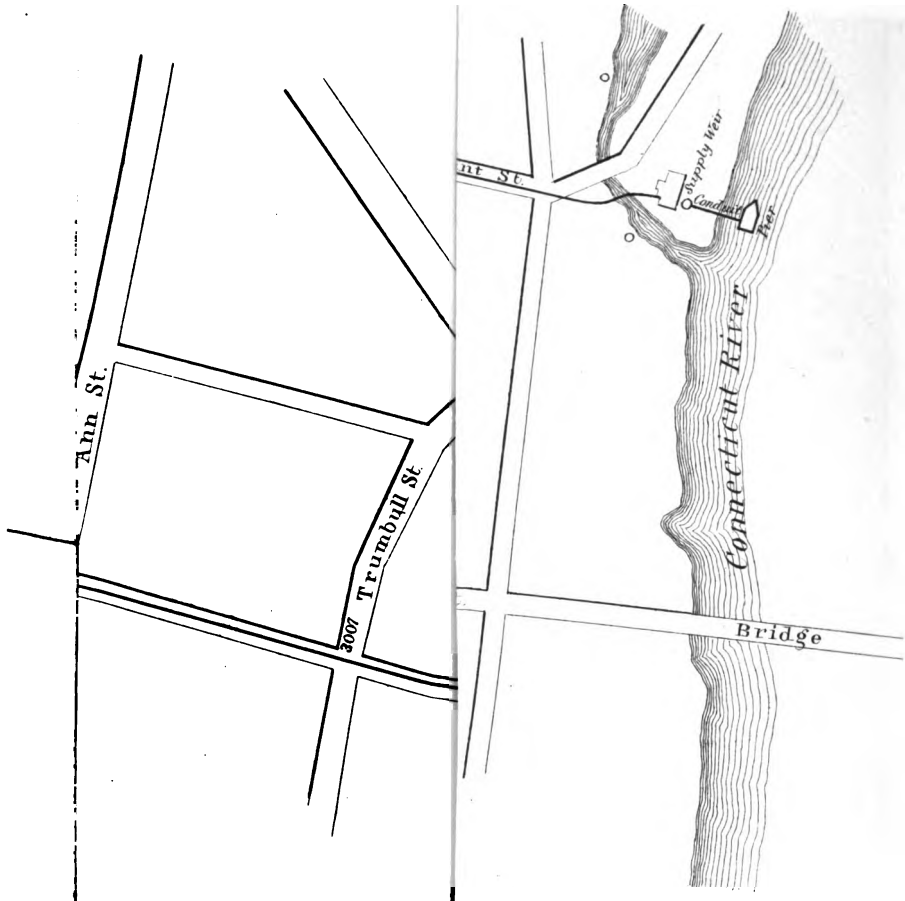
SHEET I.

Figures up[illegible]he level of Low Water.



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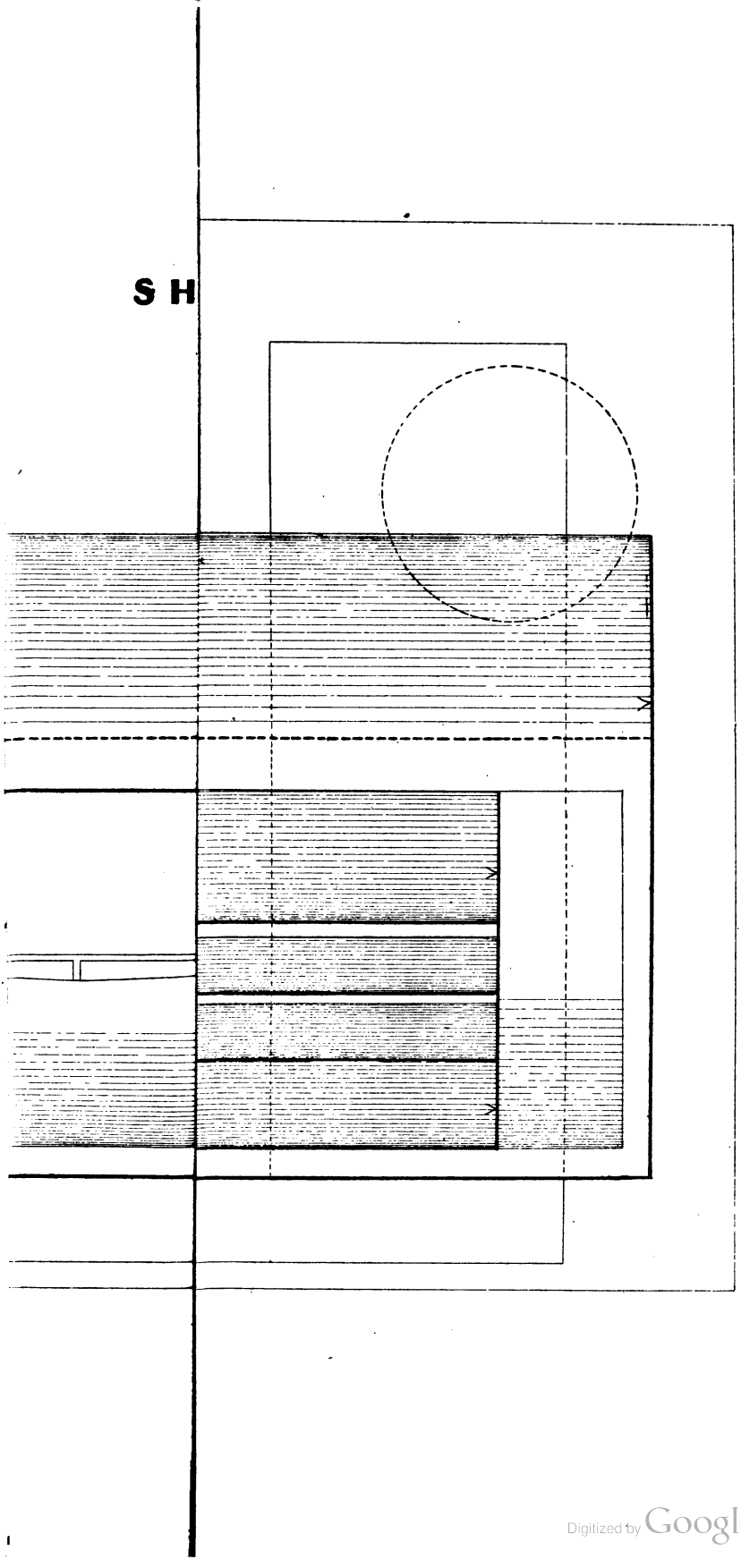

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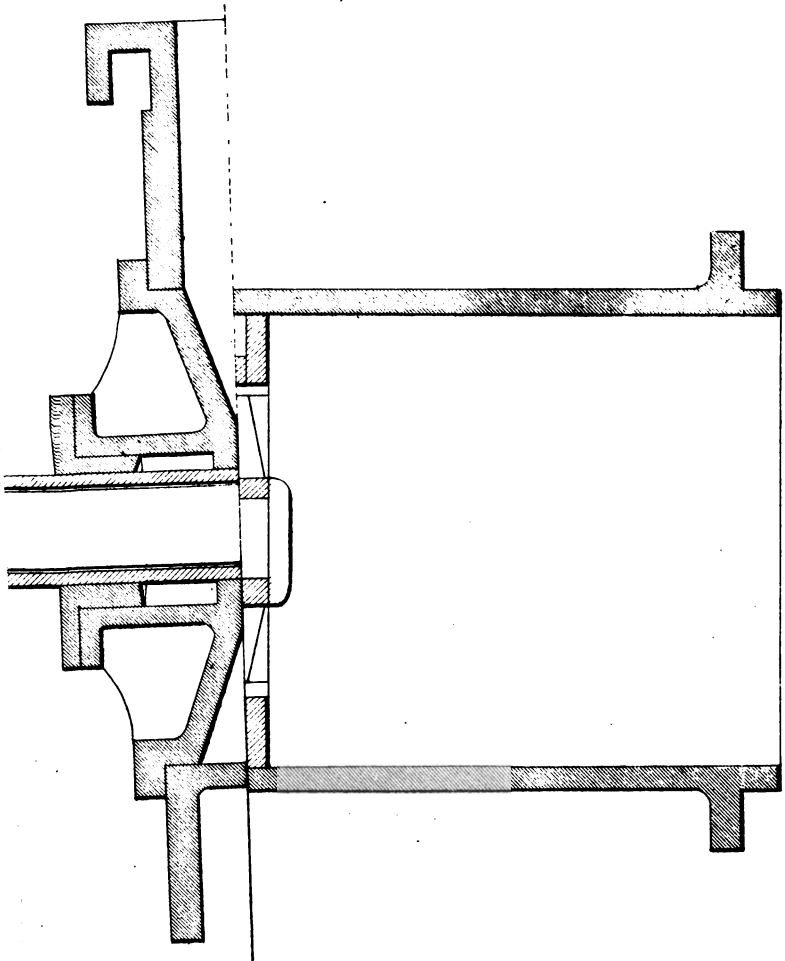

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the piston-rod of the upper one being a tube, and the piston-rod of the lower box passing through it; the valves are butterfly-valves, hinged in the middle; each piston commences its stroke before that of the other has been completed; each commencing its stroke slowly, and increasing in a short space to its uniform velocity, and at the end decreasing for like distance till it stops. Thus, whilst the lower box is rising the upper is descending, the water passing up through the valves of the upper box; but just before the lower box has completed its up stroke, the upper box has completed its down stroke, and commences to rise, the lower decreasing its velocity and the upper increasing. And *vice versa*, during the rise of the upper box the lower one descends, and commences to rise in time to relieve the upper box at the end of its stroke. Thus the stroke of one box laps on to that of the other, and of the absolute movement or stroke of 17⅞ inches of each box we have considered but 16½ inches as effective.

THE MAINS.

The water is brought from the river to the supply-well, some fifteen feet outside the building, by a pipe two feet in diameter. The pumps are arranged in plan in the form of a rectangle; a suction-pipe is brought up on each side, and the water is delivered through the pumps into a central rising main, between the pumps, which is sixteen inches in interior diameter, and is provided with a check-valve at the bottom and a small air-chamber. In its route to the Reservoir it is laid through the streets most convenient, following their courses and in general their grades, and is introduced into the bottom of the Reservoir. The length of the rising main

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is about 6,900 feet. By reference to Sheet 1 the position of the supply-well, main and Reservoir will be understood. The levels or grades of the streets above the base of low-water are given in red figures at different points.

The Reservoir is nearly rectangular in form, with earth banks and an interior puddle-bank of clay: the inside slope is protected by rubble.

Sheet 4, represents plan of the Works at Belleville.

Sheet 5, represents plan and sections of the boilers.

The boilers, four in number, are of the usual Cornish pattern, well covered; the chimney is high, and draft good, and, as at Hartford, is controlled by a damper. But three boilers were used during our experiments.

The steam connections were all felted.

The Engine is a single acting Cornish Engine of $80\frac{3}{16}$ inches diameter of cylinder, and a maximum stroke of 11 feet. The cylinder is protected by a steam jacket; the injection water is taken from the rising main.

The plunger of the pump is $34\frac{3}{4}$ inches diameter, and the stroke the same as that of the Engine.

The water is introduced from the river by a culvert some 375 feet in length, into the supply well which is beneath the Engine house.

The rising main is 36 inches interior diameter, with a check valve, some 10 feet vertical height above the top of the pump chamber; its direction will be understood by Sheet 4. It enters the Reservoir level with the bottom, is turned up with a curve, and discharges with an overflow 3 feet below the top of the bank. About 300 feet north of the Reservoir there is a summit from which, on one side the main

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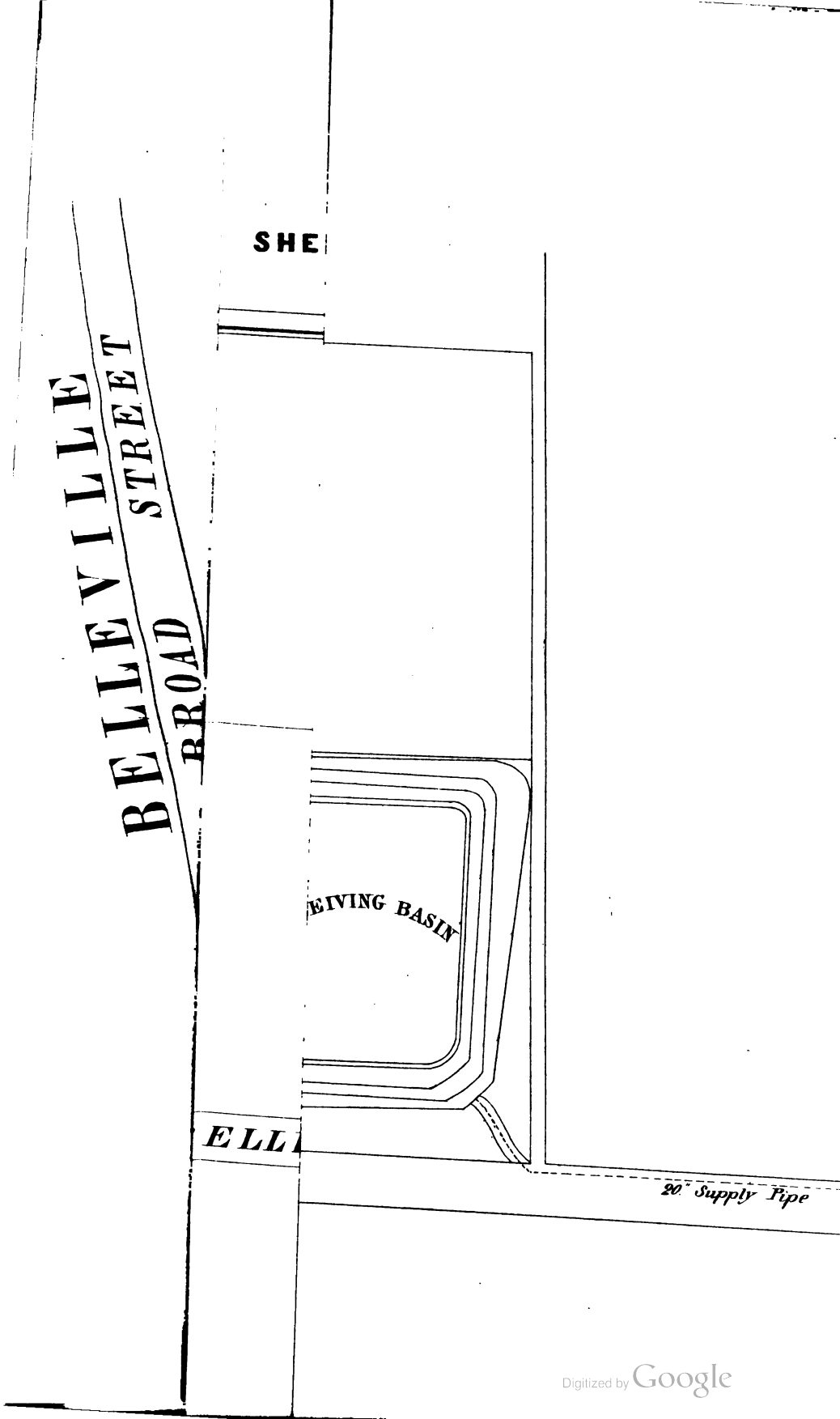

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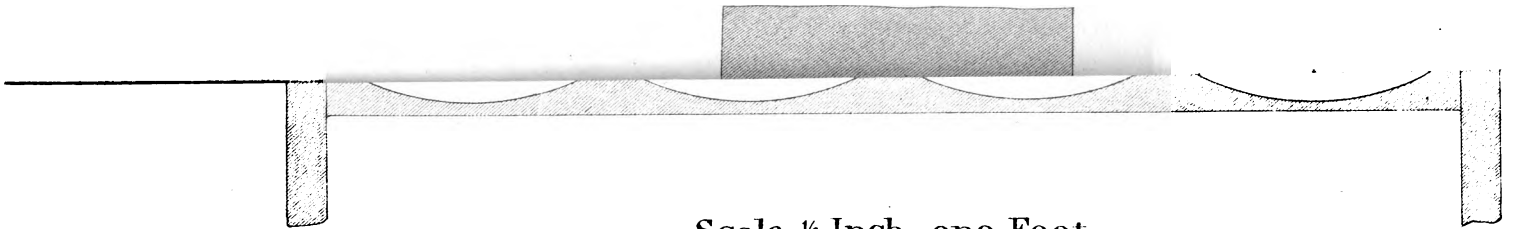
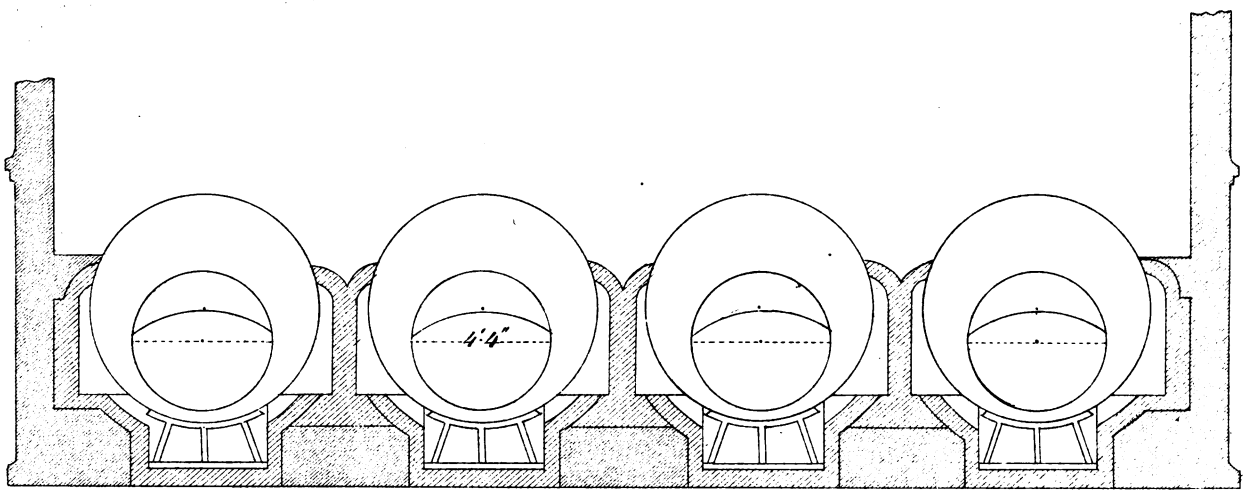


Scale ⅛ Inch=one Foot



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descends towards the Engine house, and on the other it falls about 18 inches to the level of the bottom of the Reservoir.

The whole length of the pipe is about 2,300 feet.

The Reservoir has earthen banks, with an interior puddle wall, and lined with brick 4 inches in thickness laid on a bed of cement plaster.

MODE OF CONDUCTING EXPERIMENTS.

HARTFORD.

Previous to the commencement of the trial the boiler was fired for a considerable length of time, sufficient to thoroughly heat the brick work and the stack; the fire was brought into a fair average condition, the height of water in the boiler to the proper line, and the steam to its usual working pressure; these were maintained as nearly constant as possible, during the course of the experiment, and left in the same condition at its close.

The height of the water in the boiler was taken by a glass guage.

The coal was weighed, in lots generally of 200 lbs., on scales tested and certified to, by the sealer of weights and measures of the city.

To measure the quantity of water evaporated by the boiler, a tank was provided into which the feed water was delivered and measured by accurate gauges attached to the tank, and temperature noted; this was then supplied to the boiler by a Worthington steam pump. The steam from this pump was passed through a coil in the tank, condensed, and the water discharged outside, in this way abstracting almost entirely the heat used to drive the pumps, and restoring it to the boiler.

In estimating the evaporation by volumes, this steam

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should be taken into consideration, but as the loss in this way is trifling, and unimportant to the comparative values of the results obtained from the two Engines, it has been neglected.

At the Engine, indicator cards were taken every half hour, in the first experiment, at the top only, but in the second experiment at both ends of the cylinder. At each half hour, also, the number of strokes both of Engine and pumps, the pressure on the rising main, the vacuum on the suction, the height of water in the supply well, the height of water and pressure of steam in the boiler, were noted. At the Reservoir the height of water was taken every fifteen minutes. Five observers besides ourselves were employed; their watches were brought to one standard, and the observations were simultaneous.

It was the intention to take indicator cards from the rising main, but the oscillations of the piston of the instrument were of so little range as to furnish but an indifferent card; an Ashcroft pressure gauge was therefore substituted from which the readings were taken. At a subsequent date indicator cards were taken from the pump chambers; the water in the Reservoir and supply well being of about the same height as during the experiment.

BELLEVILLE.

The same course was followed as at Hartford in maintaining a constant fire, and pressure and height of water in the boilers during the course of the experiment and to its close. The scales were tested and sealed by the officer from Newark.

Identical arrangements were also adopted for measuring the evaporating power of the boiler.

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The water condensed in the steam jacket is returned directly to the boiler, and this amount we had no means of measuring.

Indicator-cards were taken from the rising main and from top of cylinder; the vacuum beneath the piston, the counter, the length of stroke of the pump, the vacuum in the suction, the height of water and pressure of steam in the boilers, and height of water in the supply-well were noted every half-hour. The height of water in the Reservoir was taken every fifteen minutes. The indicator-cards from the rising main were taken by a continuous movement connected with clock work; and at a subsequent date indicator-cards were taken, as at Hartford, directly from the pump-chamber, and also vacuum-cards from beneath the piston of the Engine, to ascertain the action of the lower valve.

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During the second experiment at Belleville, the coal being exposed to the rain, became wet; at 10 : 30 A. M., 319 lbs. of coal were weighed and placed in the fire-box of the boiler not in use. At the conclusion of the experiment, 2 : 30 P. M., it was drawn, and although not entirely freed from moisture, the same coal weighed but 300 lbs.; 6.3 per cent. have therefore been added to the evaporation and duty. The injection-water at Belleville was taken from the main, but having no means of estimating it accurately, it is not included in the duty as given in the above table.

TABLE III.

Comparison of capacity of the Pumps per stroke, with the absolute discharge, and the height as indicated by gauges, with the height as determined by the level and by observation.

NAME	No. of Experiment	CAPACITY OF STROKE		HEIGHT		
		By Measure	By Discharge	By Level	By Gauges at Pumps	By Gauges on Mains
		Cub.ft.	Cub.ft.	Feet.	Feet.	Feet.
HARTFORD.	1st.	20.532	19.665	119.063		139.651
	2d.	"	19.259	118.159		137.678
BELLEVILLE.	1st.	72.051	65.465	159.824	166.834	166.157
	2d.	71.827	66.058	159.087		164.556

The pressures are converted into feet by multiplying by 2.3.

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TABLE IV.

Duties of the pumping machinery reduced to a common standard of evaporation of 10 lbs. of water per lb. of coal, from the temperature of 100 deg. Fahr.

NAME	WATER	Power Exerted on Piston	WORK DONE		Effective Duty at Reservoir	Duty by Cornish Mode
			At Pumps	At Rising Main		
Hartford	by Measure..	65.595.442	.....	57.167.882	45.851.390	54.203.807
2d experiment.	by Volumes..	85.614.865	.....	74.495.969	59.844.852	70.746.360
Belleville ...	by Measure..	85.738.277	70.349.272	69.469.353	61.444.476	66.810.510
2d experiment.	by Volumes..	113.187.809	92.871.939	91.576.610	81.116.227	88.200.223

Belleville, 2d experiment, with an increase of 6.3 per cent. to compensate for the wet condition of coal.

Standard of Evaporation—10 Lbs. of Water per Lb. of Coal from the Temperature of 100 Deg. Fahr.

Belleville ...	by Measure..	91.139.788	74.781.276	73.845.922	65.315.478	71.019.572
2d experiment.	by Volumes..	120.318.641	98.722.871	97.345.936	86.226.549	93.756.837

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EXPLANATION OF TABLES.

Table I. contains the evaporation of the boilers in the different experiments, together with the necessary description and dimensions.

Columns 1 *to* 9, inclusive, are sufficiently explained in the captions of the columns.

In reducing cubic feet of water to lbs.—column 10—the weight of a cubic foot at different temperatures has been taken from table, p. 29, in Francis' "Lowell Hydraulic Experiments," or from an extension of the table when necessary.

The conversion of the evaporations from the observed temperature to that from a standard of 100 deg., has been calculated from the English Admiralty formula:

"1212 deg. minus observed temperature, ÷ 1212 minus standard temperature, X" actual evaporation," = Evaporation from standard temperature.

Thus, in 1st experiment at Hartford:

$$\frac{1212 - 100.5}{1212 - 100.} \times 10.019 = 10.015.$$

To determine the evaporation by volumes, we have determined the net capacity of the cylinder, and the clearances, and the final pressure, and have divided the capacity by the volume corresponding to the final pressure. At Belleville, the equilibrium-valve closes before the completion of the up stroke, and a portion of the steam is retained in the cylinder; this amount has also been determined from indicator cards and tables of volumes, and the amount deducted from the capacity as determined above.

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BY MEASURE.			BY VOLUMES.		
tion	Evaporation ℔ ℔ of Coal.	Equivalent Evaporation ℔ ℔ of Coal from standard temp. 100.°	Total Evaporation from temp. 32°	Evaporation ℔ ℔ of Coal from temp. 32°	Equivalent Evaporation ℔ ℔. of Coal from standard temp. 100°
	LBS.	LBS.	LBS.	LBS.	LBS.
100.°5	From temp. 100.°5 10.019	10.015	2297.664	5.7442	6.0946
84.°5	From temp. 84.°5 10.810	10.961	8841.781	7.915	8.398
91.° 7	From temp. 91.° 9.700	9.778	12751.072	7.060	7.491
92.°3 4	From temp. 92.°3 9.816	9.884	24867.465	7.057	7.487
.....	.....	10.507	.....	.....	7.960
	11	12	13	14	15

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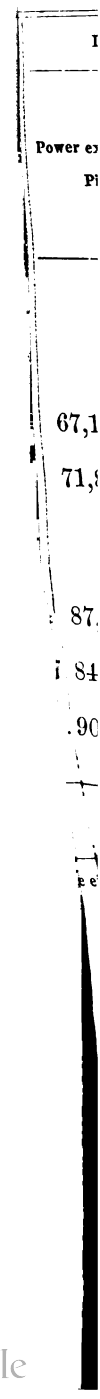

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DUTIES, OR POUNDS LIFTED ONE FOOT HIGH WITH ONE HUNDRED POUNDS COAL

Power exerted upon Piston	Work done at Pumps	Work done at Rising Main	Effective duty, or Weight of Water delivered at Reservoir	Duty according to Cornish Rule
67,171,604	.....	55,068,516	44,200,903	51,865,914
71,899,664	.....	62,661,715	50,257,707	59,412,793
87,832,671	72,115,396	71,801,323	62,515,827	68,804,844
84,743,713	69,533,221	68,563,409	60,731,719	66,035,507
90,082,567	73,913,814	72,822,903	64,557,817	70,195,744
15	16	17	18	19

e eburs and nine minutes.

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The volumes corresponding to a given pressure have been determined from the Formula, page 75, and the Table, page 76 of Pambour's "Theory of the Steam Engine." The cubic feet of water thus found by the formula are referred to an initial temperature of 32°, and to bring the result to a comparison with that obtained by measure we refer it by the English formula above given, to the same standard of 100 degrees.

It will be observed that the evaporation by volumes per pound of coal, *columns* 14 and 15, in the first experiment at Hartford, is much less than the subsequent experiments; this is owing to the less quantity of steam used in the upper end of cylinder, from which alone cards were taken in the first experiment, and if addition were made in proportion for the excess of steam absolutely found in the up stroke in the second experiment, the difference then in the evaporation would be trifling.

Table II. is the work done, or duties in pounds lifted one foot high with 100 lbs. of coal.

In *column* 12 of the Belleville experiments, it will be observed that the average length of stroke is not the same in both trials; the stroke of the Cornish Engine is not constant and defined; it was therefore necessary to measure the stroke, which was done by a sliding gauge every half hour simultaneous with the other observations.

The heights, *column* 14, are determined by measures referred to a base of low water.

Column 15. The power exerted upon the piston was determined from the average pressure taken from the half-hourly

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indicator cards, from the area of the piston, the length of stroke, and the number of strokes per 100 lbs. of coal. At Belleville the average pressure above the equilibrium line is taken from the indicator cards from the top of the cylinder, and the pressure below the equilibrium line from the observed vacuum, and from indicator cards beneath the piston.

Column 16. Work done at pumps.

The pressure on the pump pistons is determined by an average of indicator cards, which is multiplied by the area of the piston, or plunger, by the length of stroke, and by the number of strokes per 100 lbs. of coal. At Hartford cards were taken above the upper box, and between the boxes, to which is added the vacuum of the suction pipe, and the pressure incident to the difference of level between vacuum gauge and indicator. The net area of each piston is multiplied by its average pressure and suction, and the average of the two multiplied by the length of stroke of each, by the number of pumps, and by the number of strokes per 100 lbs. of coal consumed.

Column 17. Work done at Rising Main, calculated from the average pressure on the Rising Main, as shown by a pressure gauge at Hartford, and by indicator cards at Belleville, to which is added the average vacuum on the suction, and the pressure due to the difference of level between the pressure and vacuum gauges, multiplied by the average net area of the pump pistons at Hartford, and by the area of the single plunger at Belleville, by the stroke, and by the number of strokes per 100 lbs. coal.

Column 18. Effective duty, or weight of water delivered at the Reservoir. This is the absolute weight of water delivered at the Reservoir, obtained by multiplying the cubic

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contents as gauged at the Reservoir, by the heights obtained from level and from observation.

The heights taken at the Reservoir were observed with great nicety,—a scale with a sharp point in a glass tube being used at Hartford, and a hook-gauge (obtained from Mr. Francis of Lowell) at Belleville.

The temperature of water received in the pump wells was noted, and found the same at both places—32° Fahr. The weight of a cubic foot is reckoned at 62.375 lbs.

The leakage at the Reservoirs was tested, and an addition has been made to the measures as gauged at Hartford, for a small leak, but no addition has been made at Belleville; on the contrary a small amount has been subtracted in the second experiment for the effect of rain.

At 3: 30 A. M., a fall of rain commenced and continued throughout the trial; this rainfall, at the level of the Reservoir was carefully gauged, and found to be .03 foot, which is therefore multiplied by the area of the Reservoir and the amount deducted from the contents gauged during the whole experiment.

Column 19 is the duty according to the Cornish rule; that is, reckoning each stroke of the pump at the full throw of its piston or plunger, and making no allowance for leaks through valves, and pistons, or lap of strokes at Hartford, or for other losses of any description.

It will be observed upon examination of Table I. that the evaporation per pound of coal from the boilers at Hartford and at Belleville differs to some extent, and as it is desirable to compare the efficiency of the machinery proper, independent of the economy of the different boilers, Table IV. was prepared, in which the absolute evaporation of the

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boilers is eliminated, and the relative efficiency of the machinery shewn. The calculations are made both from the water evaporated by measure, and by volumes.

The Table is calculated thus: a standard boiler is assumed, the evaporation of which is 10 lbs. of water per lb. of coal, and the evaporation in both cases is brought to the standard, which is in effect assuming that at both places the Engines were supplied with steam by Boilers evaporating 10 lbs. of water per lb. of coal; this being the case whatever difference there may be in duty, is due to the machinery alone, by which the result is effected, and is shown by a simple inspection of the Table.

As the second experiment in both trials is that which we consider the most reliable, Table IV has been calculated for these experiments only.

Appended to Table IV. is a Table showing the results obtained at Belleville, increased 6.3 per cent. for the wet condition of the coal.

With regard to the shorter duration of the experiments at Hartford, there was no separate distributing Reservoir at that place, consequently during the continuance of the experiment, the water must necessarily be shut off from the city, and of course the experiment tried in the night: the duration of the second experiment, 8½ hours, being the longest time that the Superintendent of the works thought it prudent to shut off the supply.

At Belleville on the contrary, there was a large distributing Reservoir, independent of the receiving Reservoir, and the duration of the trial there, was as long as we thought necessary.

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That the modes of obtaining many of the results in the Tables may be the better understood, we subjoin *fac similes* of three Indicator Cards, from each set obtained, these three being about an average of the set of which they are a part.

Figs. A, A′, A″, show three cards taken from the upper end of cylinder at Hartford, and *Figs.* B, B′, B″, three cards taken at the same time (by a different indicator) from the lower end. These cards require no explanation.

Figs. C, C′, C″, show three cards taken from the upper of the two pumps at Hartford; it will be observed that these upper pumps (four of them) discharge into a common delivery pipe, in which is a delivery or check-valve, common to all the pumps, hence these cards represent very nearly the pressure within the rising main.

Figs. D, D′, D″, show three cards taken from the lower pumps at Hartford; it is necessary to a proper reading of these cards to recollect the peculiar operation of the upper and lower buckets of these pumps, as before described.

Figs. E, E′, E″, give three cards taken from the upper end of cylinder at Belleville, and *Figs.* F, F′, F″, are three cards (taken by the same indicator) from the lower end of the cylinder on a subsequent day, as already mentioned.

To obtain a proper representation of the action of the steam within the cylinder, it is necessary to attach a card from the lower end of cylinder to one from the upper end, placing the atmospheric line of the one card upon that of the other.*

* In the printed cuts a steam card and a vacuum card are given together.

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It should be observed, that at the time the cards were taken from the lower end of the cylinder, the vacuum was not so perfect as during the experiments; hence the vacuum line is not so far below the equilibrium line as it would be on a correct card taken during the experiment.

Figs. G, G′, G″, show three cards taken from the rising main at Belleville, as already described; it will be observed that the indicator returns partially, but not wholly, to the atmospheric line at the termination of each stroke; this effect is produced by a check-valve in the rising main, placed a few feet above where the indicator was attached; this valve of course relieved the indicator of the pressure of all that portion of the column of water above the valve, while the pump was making its up stroke.

Figs. H, H′, H″, are three cards taken from the pump on a day subsequent to that of the experiment; but, as at Belleville the rising main is carried up through the water in the Receiving Reservoir to a point above its highest level, the head upon the pump thus always remaining the same; that portion of the card above the atmospheric line is a true representation of the resistance above the pump at all times.

As there was a rise and fall of the water in the supply-well corresponding to the rise and fall of the tide in the river, the vacuum of the card would vary; therefore in estimating the duty or work done at the pump, the actual level of the water below the pump was taken from observations during the experiments, instead of taking the vacuum as shown by the pump cards.

During the course of these experiments there was undoubtedly more care in firing, and more attention given to

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the condition of the machinery, than would be the case in ordinary daily work, and we are of the opinion that on this account a deduction of ten per cent. should be made from the result set forth by the tables to obtain a fair representation of the duty in their regular ordinary operation.

It was our intention in the Report to have investigated fully the comparative value of the works at the two places in a commercial point of view, that is, taking into consideration *first cost* as well as *duty* and *working expenses*. At our request, therefore, the Superintendents at both places furnished us statements of the cost of the different machines, foundations and structures; but on examination we find it impossible to determine satisfactorily what proportion of the last two items is properly chargeable to the machinery, and what to the exigencies of the locality, and what to arrangements for extended supplies.

Thus, at Hartford the foundations are upon piles driven into quicksand, requiring extensive sheet piling; at Belleville the foundations are upon a sandstone ledge.

At Hartford, as the river is subject to high freshets, the pump and air-chamber, well and engine-room, are protected by a curb of solid masonry, carried above the high water-mark; no such precautions were necessary at Belleville, but foundations were there laid for an additional engine, looking to the necessity of a greater supply of water hereafter.

In view of these many diversities, we have compared the two engines commercially, merely with regard to their duties. Thus, by reference to the columns of work done at the rising main—Table II., experiment 2d—at Hartford, it will be seen that the duty is, in round numbers, sixty-two millions; at

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Belleville—2d experiment—with the addition for the condition of the coal, seventy-two millions.

If we estimate the value of coal delivered at the works at $6 per ton, of 2,240 lbs., then the cost of one hundred millions of duty would be at

Hartford..	$0.432
Belleville .	$0.372
Or in favor of Belleville.....	.06 per 100 millions of duty.

Each Engine at Brooklyn is required to raise ten millions of gallons, of 8 lbs. each, 170 feet high, per day, or

	13,600	millions	of	duty.
Add for friction of pipe 15 p. c...	2,040	"	"	"
	15,640	"	"	"

Hence 156.40 X .06 = $9.38 per day in favor of the Belleville Engine, as applied to *each* Brooklyn Engine. The year's saving, allowing 300 working days to the year, would be $2,814; or the interest at seven per cent. on $40,200, or for the two engines, as required by the contract, $80,400 00.

At the time these experiments were entered upon by us, we had great doubt as to the results that would be obtained, and knowing there was a difference of opinion among engineers and others in regard to the relative efficiency of the two modes of elevating water for the supply of cities and towns, we endeavored to conduct the experiments with the utmost care and with entire impartiality, having no other interest or object than to arrive correctly at the facts, and so report them. For this reason many checks were provided and independent observations taken, which ordinarily would

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be considered unnecessary; we believe no other course would have been just to ourselves or satisfactory to you.

In closing, we desire to express our obligations to Mr. McElroy for the valuable assistance rendered by him, both in observations and calculations; to the Water Commissioners, Engineers and others connected with the works; particularly to Mr. Bissell, the Superintendent of the works at Hartford, and to Mr. Bailey, Superintendent of the Jersey City Water Works, for the promptness with which every facility was given and assistance furnished for the prosecution of the experiments, and the more so, as it was evidently from a desire that no obstacle should be interposed to the attainment of the desired information.

Respectfully submitted,

CHARLES W. COPELAND,
W. E. WORTHEN.

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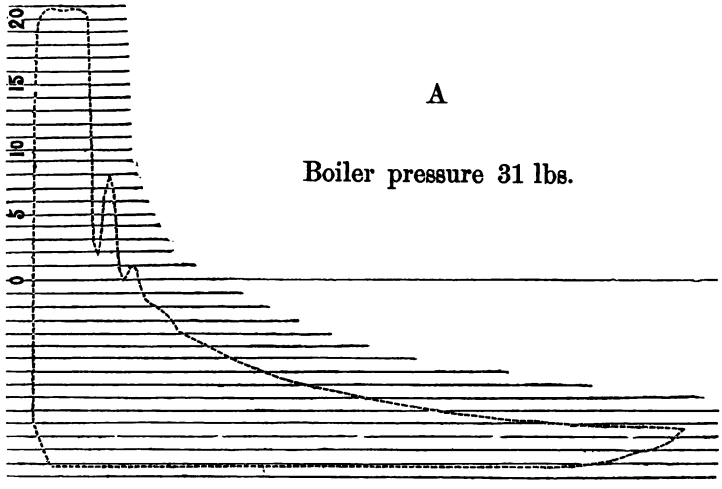
DIAGRAMS

Accompanying the Report on Belleville and Hartford Engines.

Figures A, A′, A″,
Cards from Hartford Engine, Lower End of Cylinder.



A

Boiler pressure 31 lbs.

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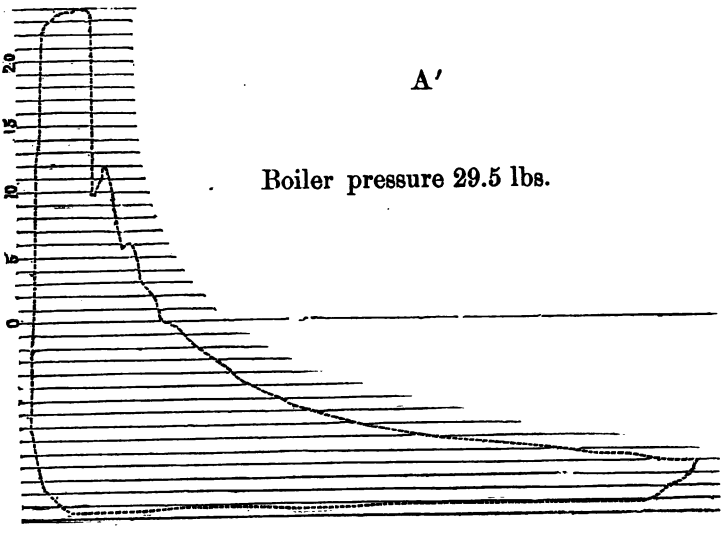
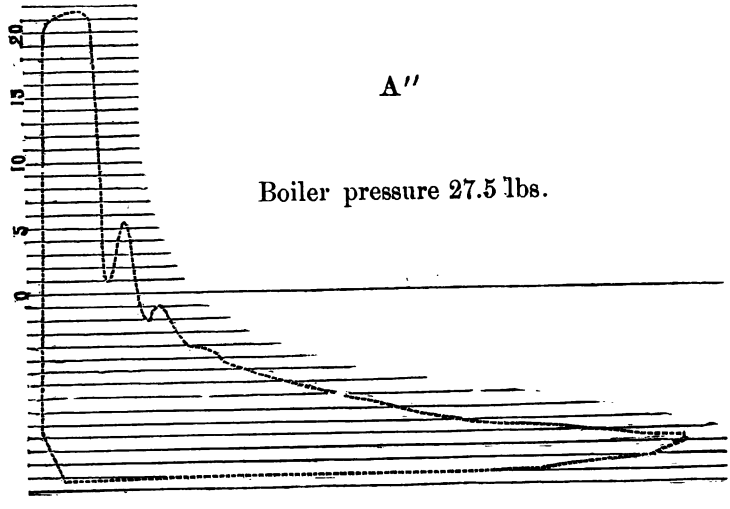


A′

Boiler pressure 29.5 lbs.



A″

Boiler pressure 27.5 lbs.

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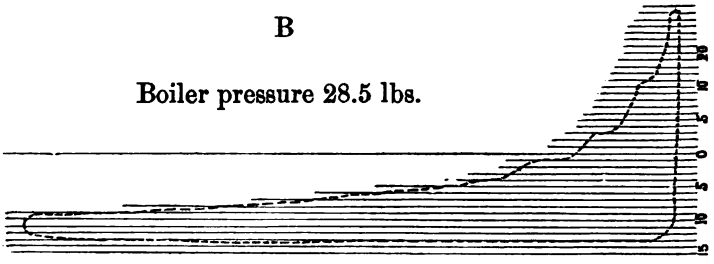
Fignres B, B′, B″,

Cards from Hartford Engine, Lower end of Cylinder.

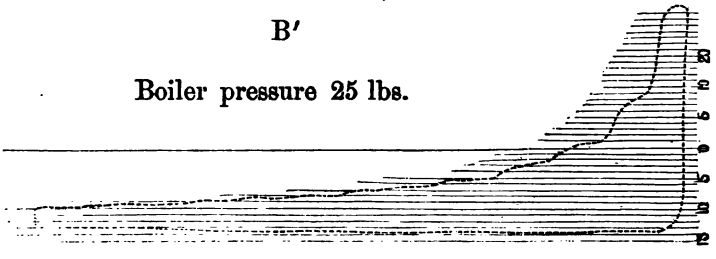
B

Boiler pressure 28.5 lbs.



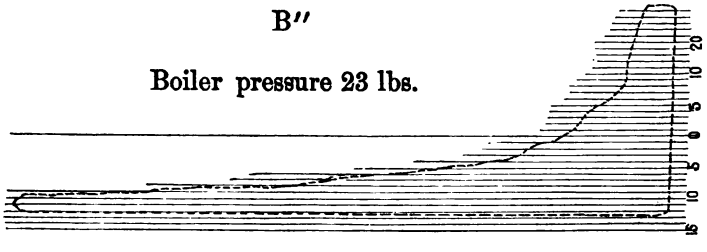
B′

Boiler pressure 25 lbs.



B″

Boiler pressure 23 lbs.



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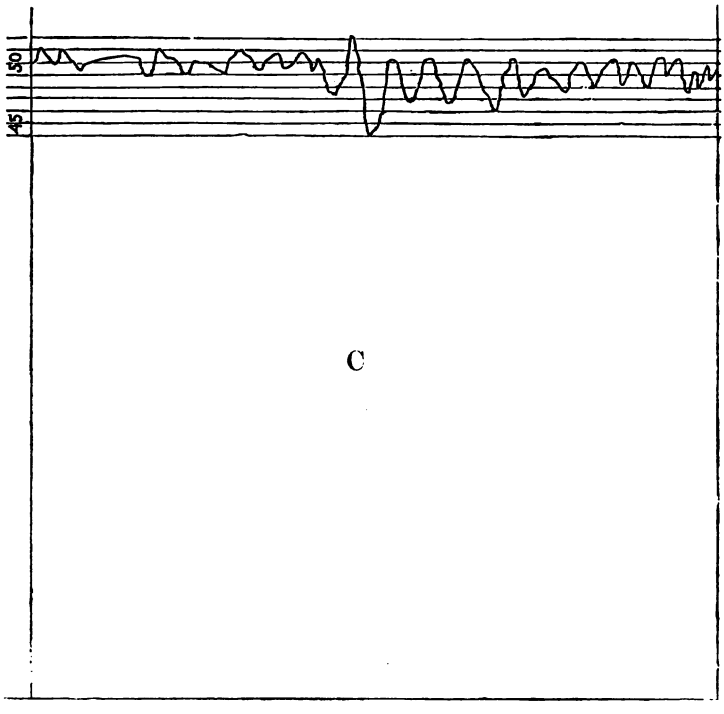
Figures C, C′, C″,

Cards from Hartford, UPPER PUMP.



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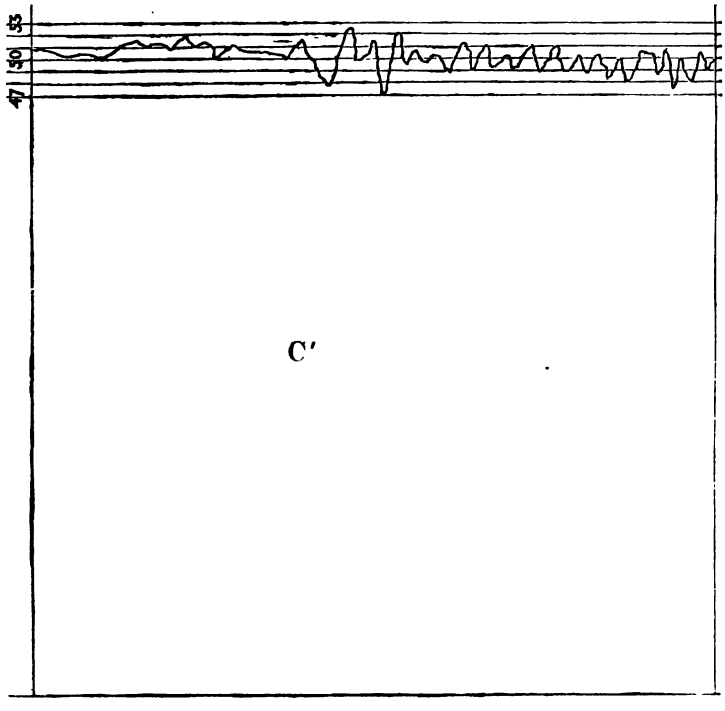

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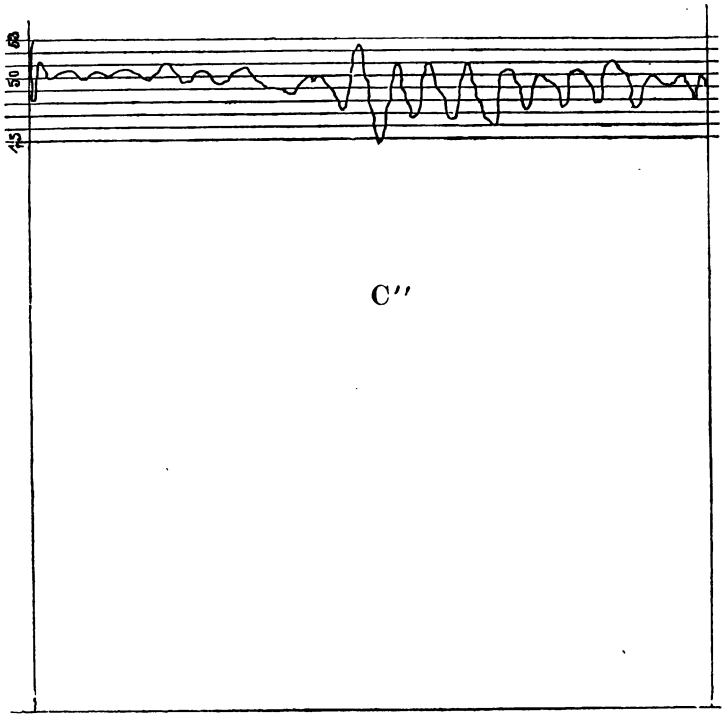

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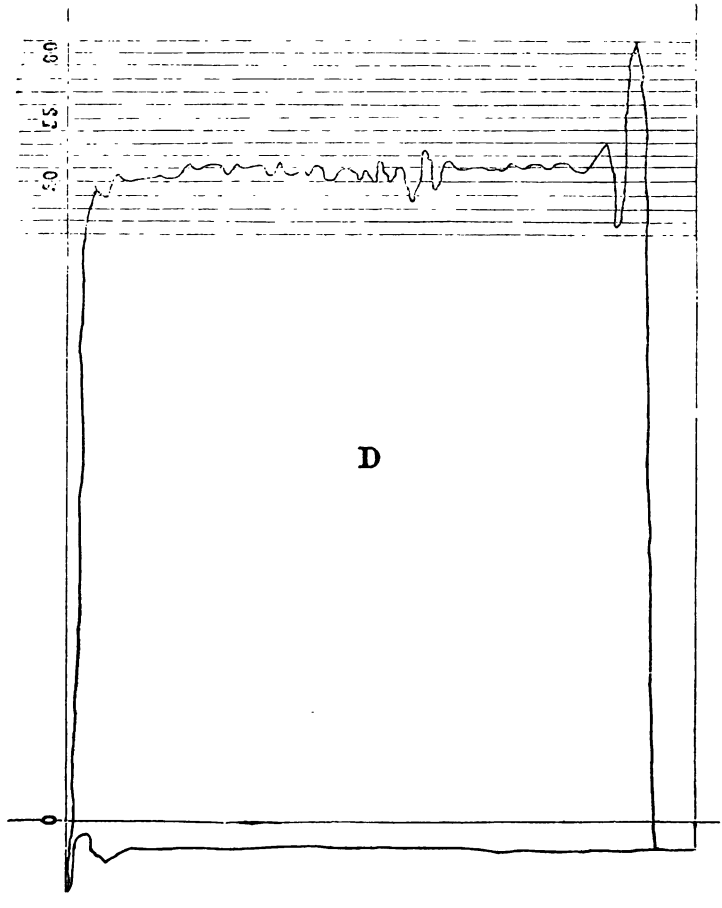
Figures D, D′, D″,
Cards from Hartford, Lower Pump.



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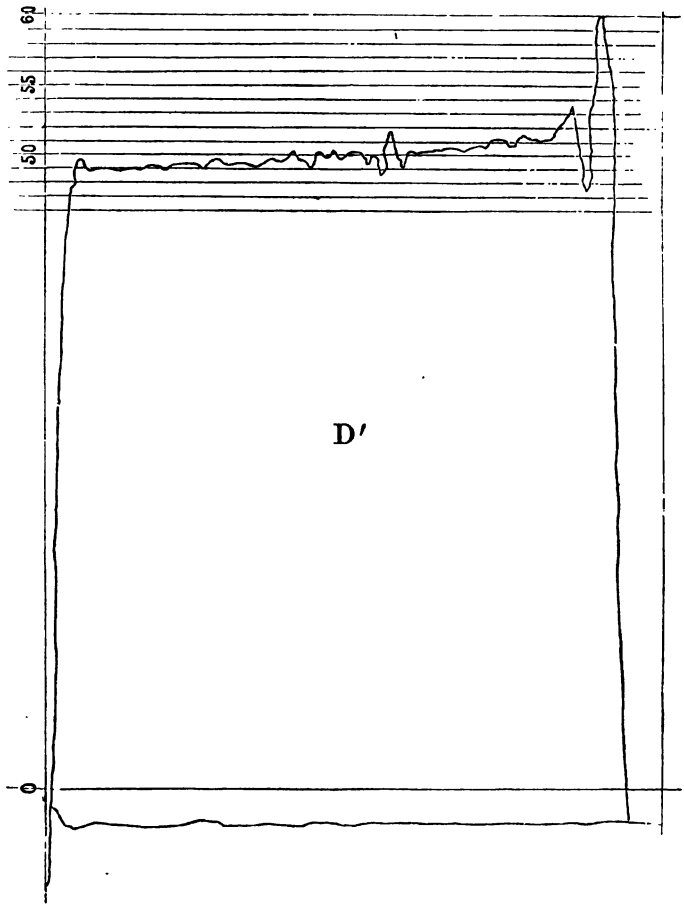

D′

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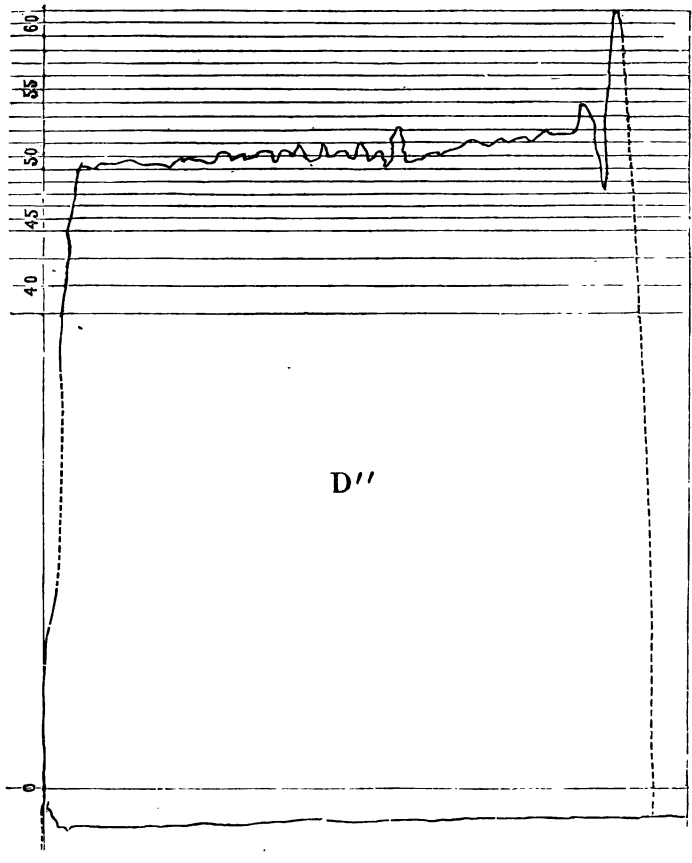

D''

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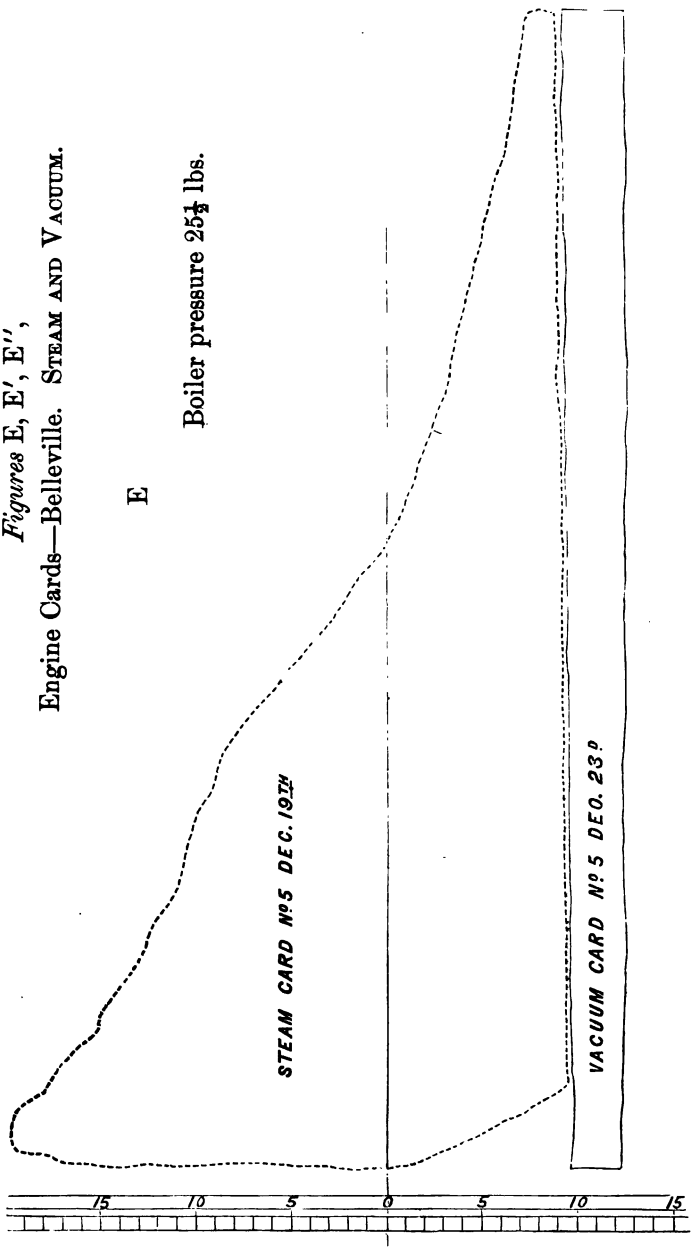
Figures E, E′, E″,
Engine Cards—Belleville. STEAM AND VACUUM.

E

Boiler pressure 25½ lbs.



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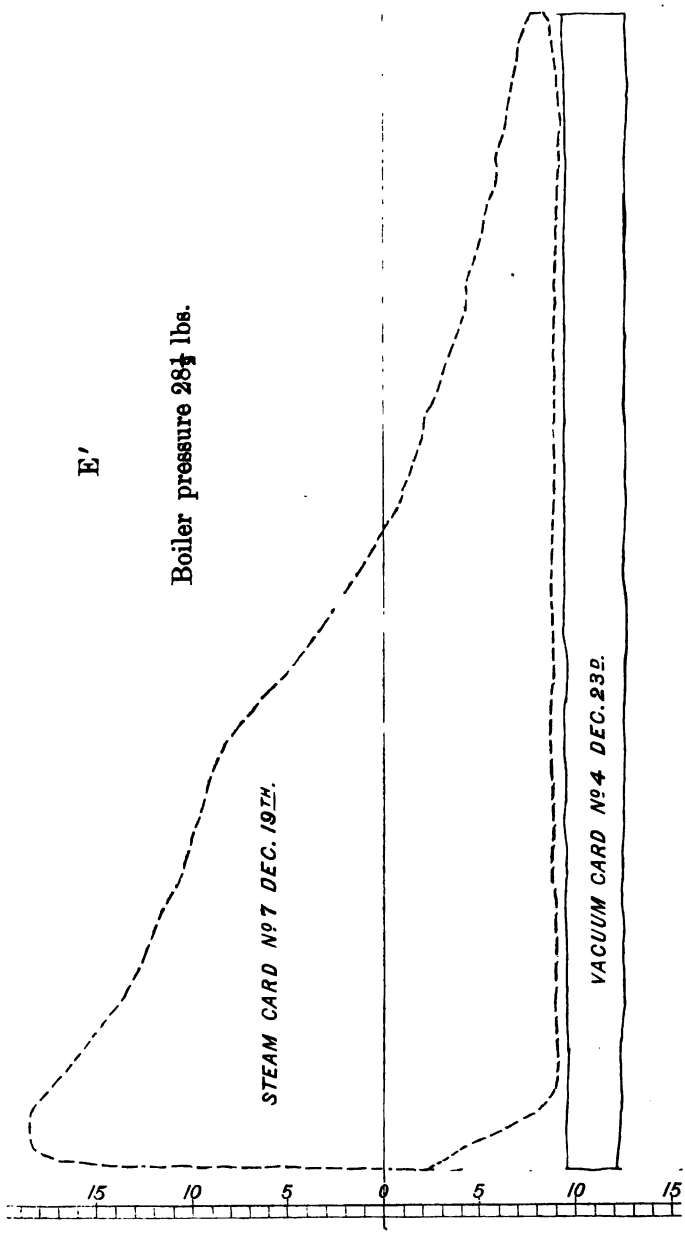

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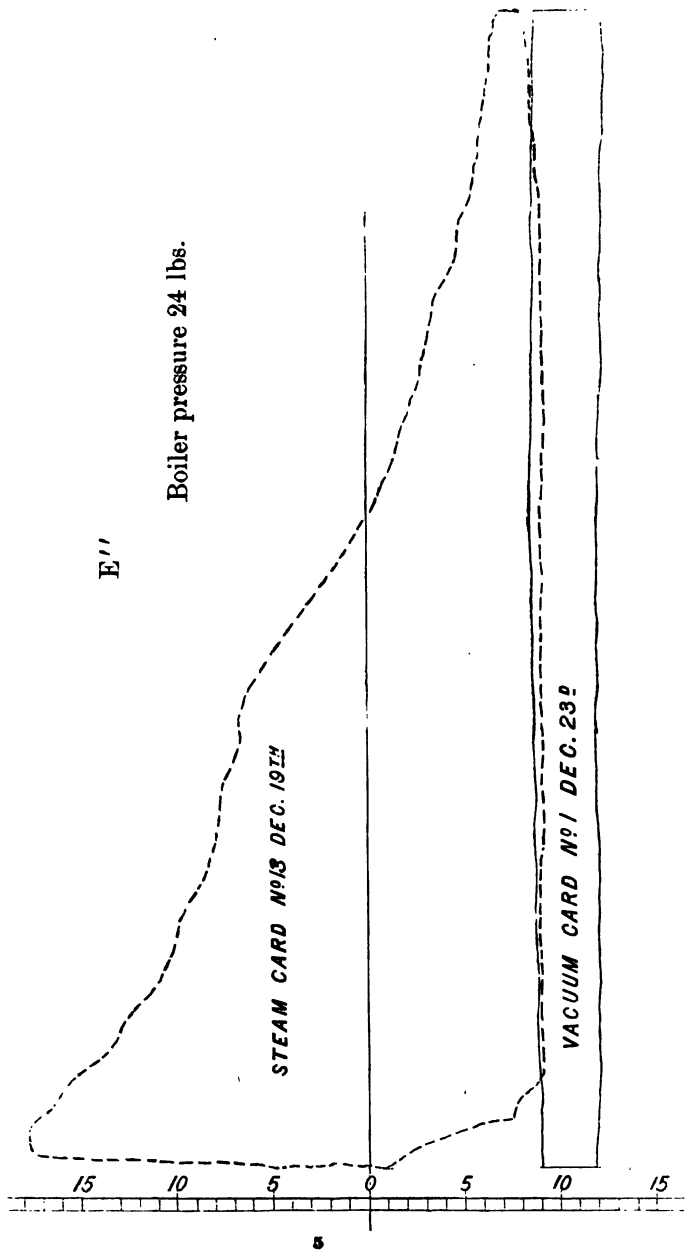

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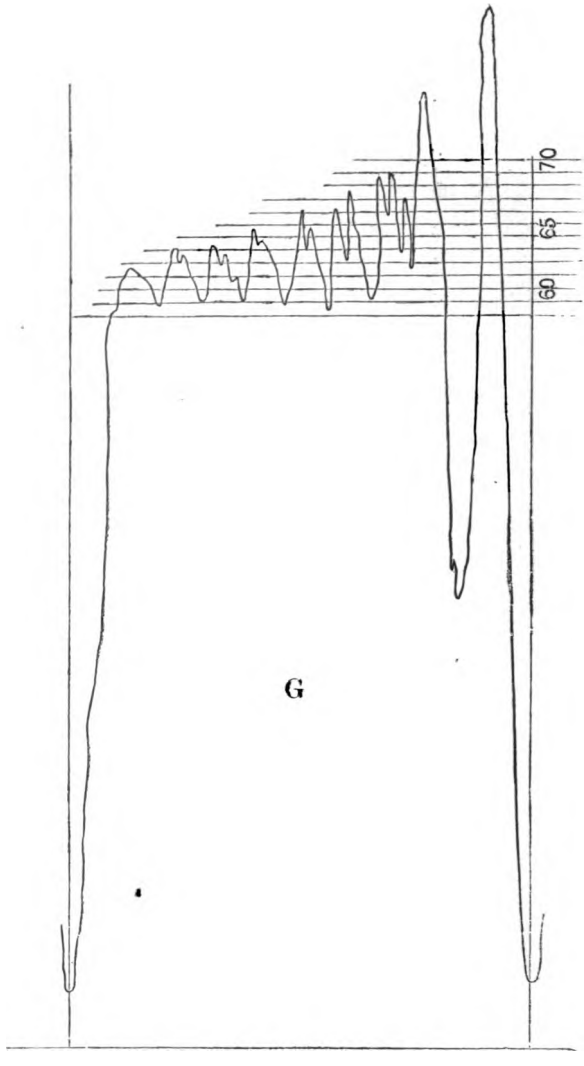
Figures G, G′, G″,

CARDS AT RISING MAIN—Belleville.



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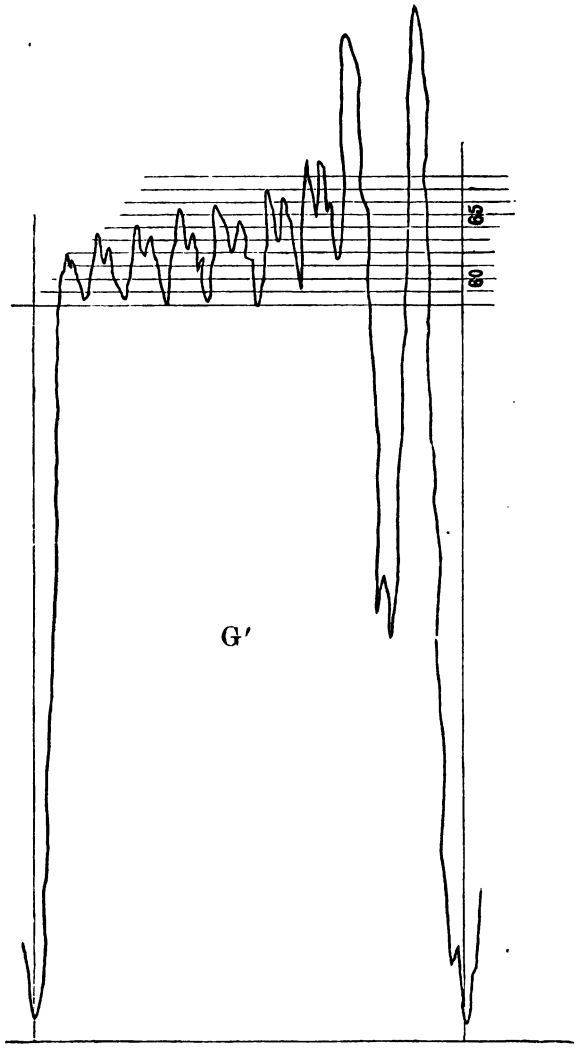

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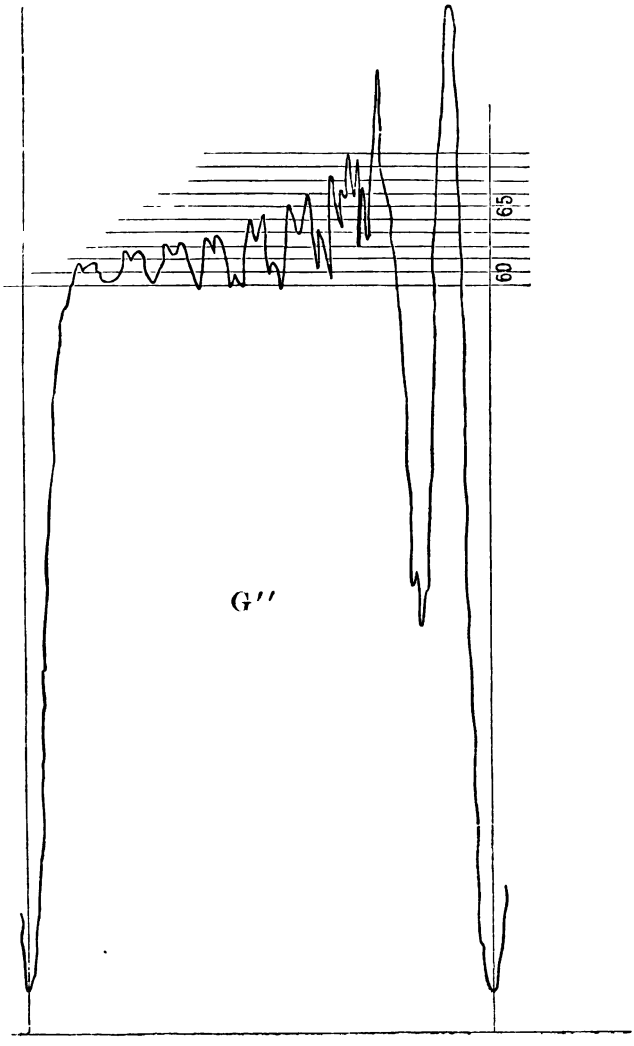

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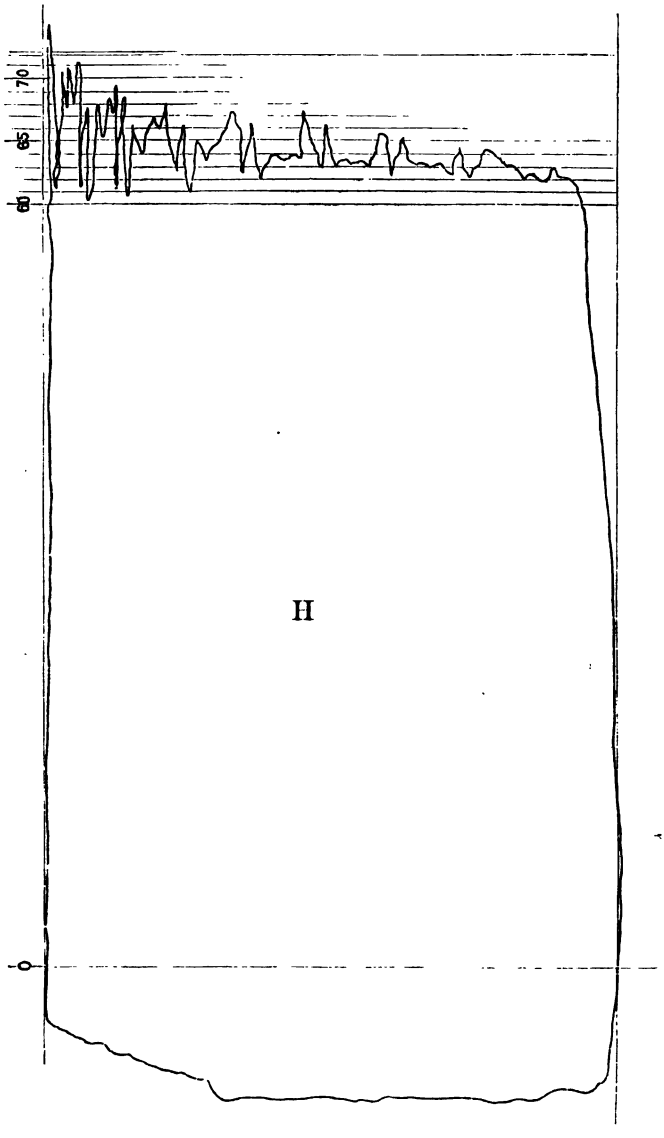
Figures H, H′, H″

PUMP CARDS—Belleville.



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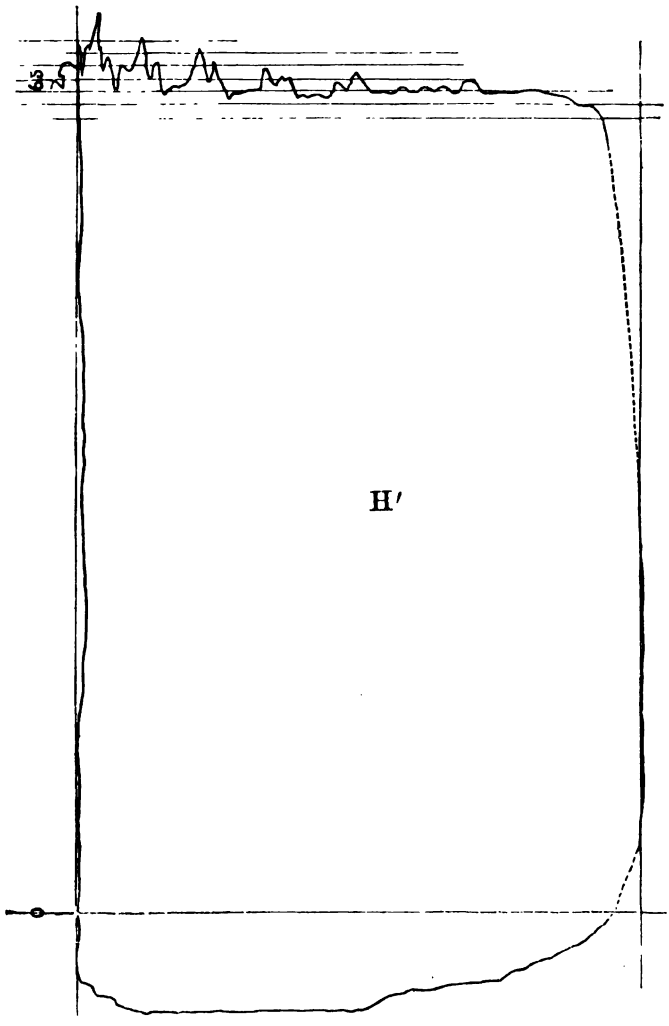

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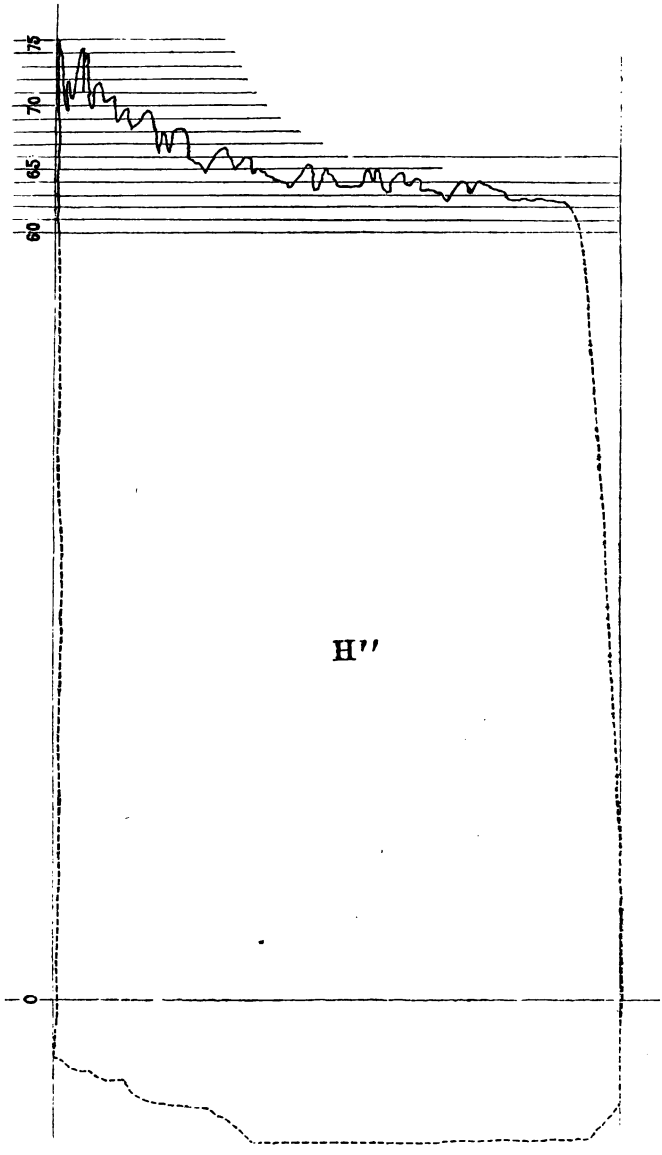

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Report by Messrs. Morris and McElroy, on the Cambridge Pumping Engine.

BROOKLYN, April 9, 1857.

SIR: The undersigned, having made an examination of the Cambridge Pumping Engine on the 30th ult., respectfully report:

That the Engine and Boiler used was taken warm, with clean furnaces, and fires started at 10: 40 A. M., noting the wood and coal used, and that the Engine was started at 11: 38 A. M. with 33 lbs. steam in the Boiler, and run until 12: 8 P. M. (with the exception of four minutes stoppage), being run down from the total coal used, of which the last charge was put in at 9: 40 P. M.

That from the firing, and other notes taken on this occasion, we have decided to assume the condition of the Boiler at 12: 30 M. and 9: 30 P. M. as uniform, for the basis of a calculation of duty, which results as follows:

Steam .....40 lbs. pressure.
Water.....uniform level.
Fire .....uniform condition.
Coal consumed.....eight equal charges, of 45 lbs. each, put in at 12: 30, 1: 35, 2: 37, 3: 38, 4: 45, 5: 45, 7, and 8: 20 P. M., being 360 lbs.
Counter (Stillman & Allen's) at 12: 30.....123077
9: 30.....133759
No. of double strokes..10682, or..21364 single strokes.
Net area of Plunger...156,6 sq. in, (rods deducted).
Length of stroke.....2.181′.
Actual lift of water (taken from Company's Report) 72.29′.

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CALCULATION OF CORNISH DUTY.

$$\frac{4.56 \text{ c. ft.} \times 62.38 \text{ lbs.} \times 10682 \text{ strokes} \times 72'.29}{3.6 \text{ bushels of 100 lbs.}} = 61{,}015{,}243$$

CALCULATION OF DUTY AT DELIVERY.

150.6 sq. in. × 2'.181 × 36.15 lbs. × 5934.44 strokes per 100 lbs. coal=70.463,750 ft. lbs.

The average pressure of the Ashcroft Guage on the delivery was	31.9 lbs.
Average suction by Indicator	4.25
Total load	36.15 lbs.

The calculations of duty are based on the notes to Table II., Report of Messrs. Copeland and Worthen, in which no allowance is made for loss of action of the pumps, and the weight of water is the same as used by them, 62.38 lbs.; we also assume that the record of coal consumption is strictly accurate, and the fire in the same condition at 12: 30 M. and 9: 30 P. M.

Respectfully yours,

WM. E. MORRIS, C. E.
SAMUEL McELROY.

JAS. P. KIRKWOOD, Esq.,
Chief Eng'r Brooklyn Water Works.

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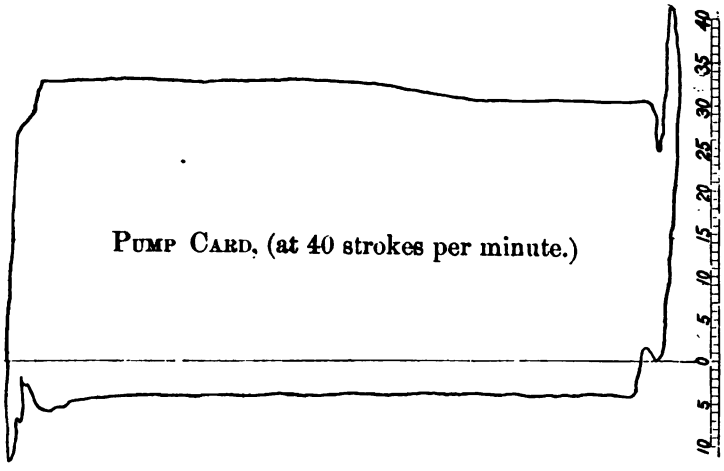
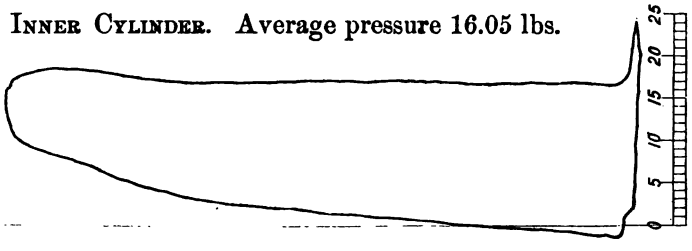
Indicator Cards accompanying the first Report on the Cambridge Pumping Engine.

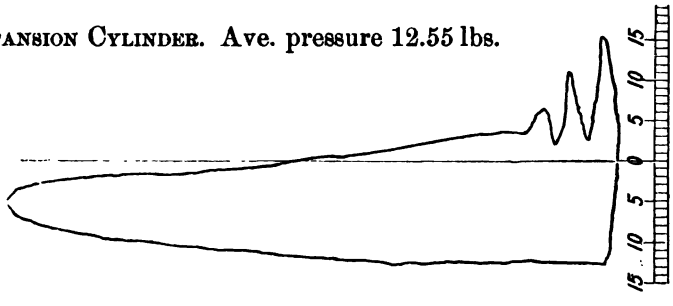


ENGINE CARDS.

INNER CYLINDER. Average pressure 16.05 lbs.



EXPANSION CYLINDER. Ave. pressure 12.55 lbs.



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Report of Messrs. Graff and Smith on the Cambridge Pumping Engine.

NEW YORK, June 29th, 1857.

The undersigned having tested the performance of a Pumping Engine, erected at Cambridge, Mass., for the water works at that place, by Mr. H. R. Worthington, herewith submit the result of that test, with the data from which it was deduced.

As it appeared to be desirable that the conditions of the trial should approach as nearly as possible those of daily working practice, and the Boilers not being the subject of exclusive test, it did not seem essential that the time necessary to raise steam in them should be ascertained, nor the fuel for that purpose be noted.

The fires, Engine, and Boilers, were put into fair working condition, and run until the furnaces required fuel; the amount of the fuel in them was then carefully estimated from measurement, the intensity of the fires closely observed and the steam pressure noted, as also the level of the water in the Boilers.

The test was then commenced, and continued for the time mentioned below, care being taken, that the condition of the fires, and the pressure of the steam, should be as near as possible the same at the termination as at the commencement of the trial.

The amount of load upon the Pump was ascertained om its area, and carefully observed indications of an Ashcroft pressure guage placed upon the delivery pipe, an esti-

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timated addition being made for the height the water was drawn and forced between the center of the guage and the surface of the water in the pump well, the total pressure thus obtained being thirty-three pounds to the square inch.

The total number of strokes made by the Engine amounting to 33,678, were obtained from a counter placed upon it, and confirmed by the average of numerous counts made during the trial.

The length of stroke of the plunger (the average of thirteen careful measurements) was two and one-sixth feet.

The total coal consumed was 508.5 lbs.: the duration of the test fourteen hours forty-six minutes.

The data will therefore be as follows:

150.521 inches area X 33 lbs. = 4967.193 lbs. load upon the plunger.

33678 strokes X 2 1-6 feet = 72969 feet traveled by the plunger.

$$\text{Then } \frac{4967.193 \times 72969}{508.5 \text{ lbs.}} \times 100 = 71.278.486 \text{ lbs. lifted}$$

one foot high with one hundred pounds of coal.

Previous to the trial the scale upon which the coal was weighed, was placed in a permanent position, examined and sealed: a copy of the certificate of the sealer as to their correctness is appended hereto.

The Ashcroft guage used, was tested by the manufacturers after the trial, and their certificate of the amount of its error is also attached: the correction of this error has of course been made in the data given.

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The pump was opened, the diameters of the plunger and its piston rods measured, during which time the tightness of the delivery valves and plunger under pressure of the column of water was observed; the leakage was very small, that of the valves being just appreciable, of the plunger comparatively very little more.

Effort was made to obtain a measurement of the reservoir, with a view of ascertaining if possible, the amount of water actually delivered by the pump during stated periods, it was found, however, impracticable to arrive at any satisfactory result, on account of the irregularity of the slope sides, the unknown vacancies behind the stone lining, the absorbent character of the embankment, and the probable leakages of a reservoir of that size and description.

The Pumping Main is brought up perpendicularly above the surface of the water in the reservoir, which admits of its being seen: observation satisfied us that the water was delivered from it with great regularity, and did not contain any undue amount of air.

The clothings of the steam pipes and cylinders, although good, are not as strictly guarded in that respect as is usual with the Cornish Engines in England.

During the experiment the guages were so placed as to afford an accurate indication of frictional resistance, showing that a head of 6.05 feet was required to overcome the friction of the water through the pumps and also through the main. In other words the difference between the surveyed height and that indicated by the guage was 6.05 feet.

The general character of the design and workmanship of the Engines is quite creditable, and they appear to be simple,

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reliable, and durable; during the trial every thing worked satisfactorily, and required very little attention from the Engineer.

FREDERICK GRAFF,
ERASTUS W. SMITH.

To Messrs. J. C. Brevoort,
James P. Kirkwood,
} Committee.

This is to certify that I have tested the Platform Balance used at the Cambridge Water Works, and find it perfectly correct, according to the State standard.

Geo. P. Backus, Sealer.

Cambridge, June 26th, 1857.

Boston, June 27, 1857.

This may certify that Guage numbered 8368.55, sold J. J. Walworth & Co., June 26, 1857, was returned to the shop of the merican Steam Guage Co. this day for proof of its correctness, and found to vary one half-pound less than the true indication. It is now made to indicate correctly.

H. K. Moore,
John Bunce,
Supts. Am. Steam Guage Co.

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Office of the Woodruff & Beach Iron Works.

HARTFORD, July 4th, 1857.

JAMES P. KIRKWOOD, ESQ., CHIEF ENGINEER, &C.:

Dear Sir—Understanding that you have been further testing the working economy of the Cambridge Engine, I beg leave, in behalf of Woodruff & Beach and myself, to request your presence, accompanied by any gentlemen you may think proper to select, to witness a trial of the Hartford Engine, on any day, to be named by yourself, after next Wednesday.

The amount of facts recorded at the engine-house induces us to make this request, as they prove that the Engine is now producing a regular daily duty greater than has ever been obtained before. The increase is due to lessening the amount of friction of the pump-piston, and by an improvement in the mode of packing, discovered by myself. The change has only been made on two pumps, and the Engine now does a duty every day of 70,000,000; when the remaining two pumps undergo the same improvement, the duty as a consequence will increase in a like ratio.

The improvements lately made in the working apparatus of this style of Engine, together with the improvements in the method of packing the pump-pistons, as alluded to above, give us great confidence in stating that an Engine on our plan, now before you, would give a greater result than the Hartford Engine, and far exceeding your standard.

Your compliance with the above request, and an early answer, will confer a favor on

Yours, sincerely,

WILLIAM WRIGHT.

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It was agreed by Mr. Wright and myself that Messrs. Graff and Worthen should make the second trial of the Hartford Engine suggested above. Their report follows.

J. P. KIRKWOOD.

Report of Messrs. Graff and Worthen on the Hartford Pumping Engine.

NEW YORK, July 16, 1857.

JAMES P. KIRKWOOD, ESQ.:

According to the request of Mr. Wright and yourself, having made a trial of the Pumping Engine at Hartford, Ct., we submit the following Report of our method of conducting the experiment and the results:

The trial was commenced at 10 : 20 A. M. of the 14th inst., and extended to 4 : 7 P. M. of the 15th.

Previous to the trial the temperature of the fire-box was found to be 150 deg. Fahr., and there was a vacuum in the boiler. At 9 : 50 A. M. commenced firing with wood, using about one-sixth of a cord for that purpose, and then supplying coal to the amount of 600 lbs., when having raised 25 lbs. of steam on the boiler, at 10 : 20 A. M., the Engine was started and continued to run till the close of the experiment, when the whole of the steam in the boiler was exhausted and the steam gauge showed a zero pressure in the boiler. The experiment was conducted in this manner at the suggestion of Mr. Wright, who wished to show the value of the Engine when working intermittently. But in order to afford a comparison with the previous experiments on this

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Engine, and on the Engine at Cambridge, Mass., at 2 : 43 P. M. (14th) the state of the fires was observed, and at 2 : 35 A. M. (15th), the fires being then in the same state, the number of strokes of the pump were recorded in the interval, together with the amount of coal used. It will be seen, by comparing the results of these two experiments, that although the duty as shown by the last is larger than for the whole trial, yet it is but a small percentage, and that by running the Engine thus to the extreme at the close, the value of the coal used in firing is in a great measure made available. The pressure on the rising main was taken by an Ashcroft gauge, just above the foot-valve; this gauge compared with a mercury gauge in the engine-room agreed very nearly. The vacuum was also taken by a gauge on the suction-pipe, and the pressure on the pump pistons is obtained from an average of the observed pressures; the stroke and size of the pumps were obtained from Messrs. Copeland and Worthen's Report:

Average net area of Pump Piston..... 275.0459 inches.
Length of Stroke..... 16½ inches.

First experiment, from 10 : 20 A. M. (14th) to 4 : 7 A. M. (15th).

Coal consumed:

Firing wood, equal to, (estimated)	150 lbs. coal.		
" coal.....	600 " "		
Coal, during experiment.....	2400 " "		
			3150 lbs.
Residuum.....	501 lbs.		
Less Ashes.....	181 "		
			320
Net Coal Consumed.....			2830 lbs.

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Number of Strokes of Pump..... 10292
Average Pressure..... 60.92 lbs.
Duty per 100 lbs. Coal.....65.505.469 lbs. ft.

Second experiment, from 2 : 43 P. M. (14th) to 2 : 35 A. M. (15th), 11h. 52m.

Coal Consumed..... 1800 lbs.
Strokes of Pump..... 6892
Average Pressure..... 60.93

Duty per 100 lb. Coal..... 68.974.549 lbs. ft.

Strokes per Min., 1st Experiment..... 9.63
" " 2d " 9.68
Average Pressure on Boilers, about..... 20 lbs.
Vacuum..... 27½ in.
Temperature of Hot Well..... 102 Fahr.
Do. Water in Rivers..... 78
Average lift, about..... 120.5 ft.

The alterations in the machinery since the experiments made by Messrs. Copeland and Worthen, are as follows: the Engine has been fitted with a governor; a heater has been introduced into the exhaust, by which the feed-water is supplied hotter to the boiler; the clearances in the cylinders have been reduced, and the pump pistons have been new packed.

It was understood by us that these experiments were intended as a comparison with those made at Cambridge by Messrs. Smith and Graff, and experiment 2nd was conducted and the results calculated in the same way as by those

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gentlemen. It may not be amiss to state that the draft of the pattern from which the cams were made seems to give a somewhat longer stroke than that assumed above, but as this was taken with great care from the machines in the previous trial, and as the actual delivery of water was less than the measured capacity of the pumps, we did not feel at liberty to assume any other without testing by measure and by indicator, as was done before.

Respectfully submitted,

FREDERICK GRAFF,
W. E. WORTHEN.

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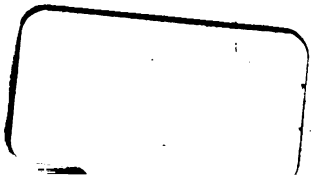

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